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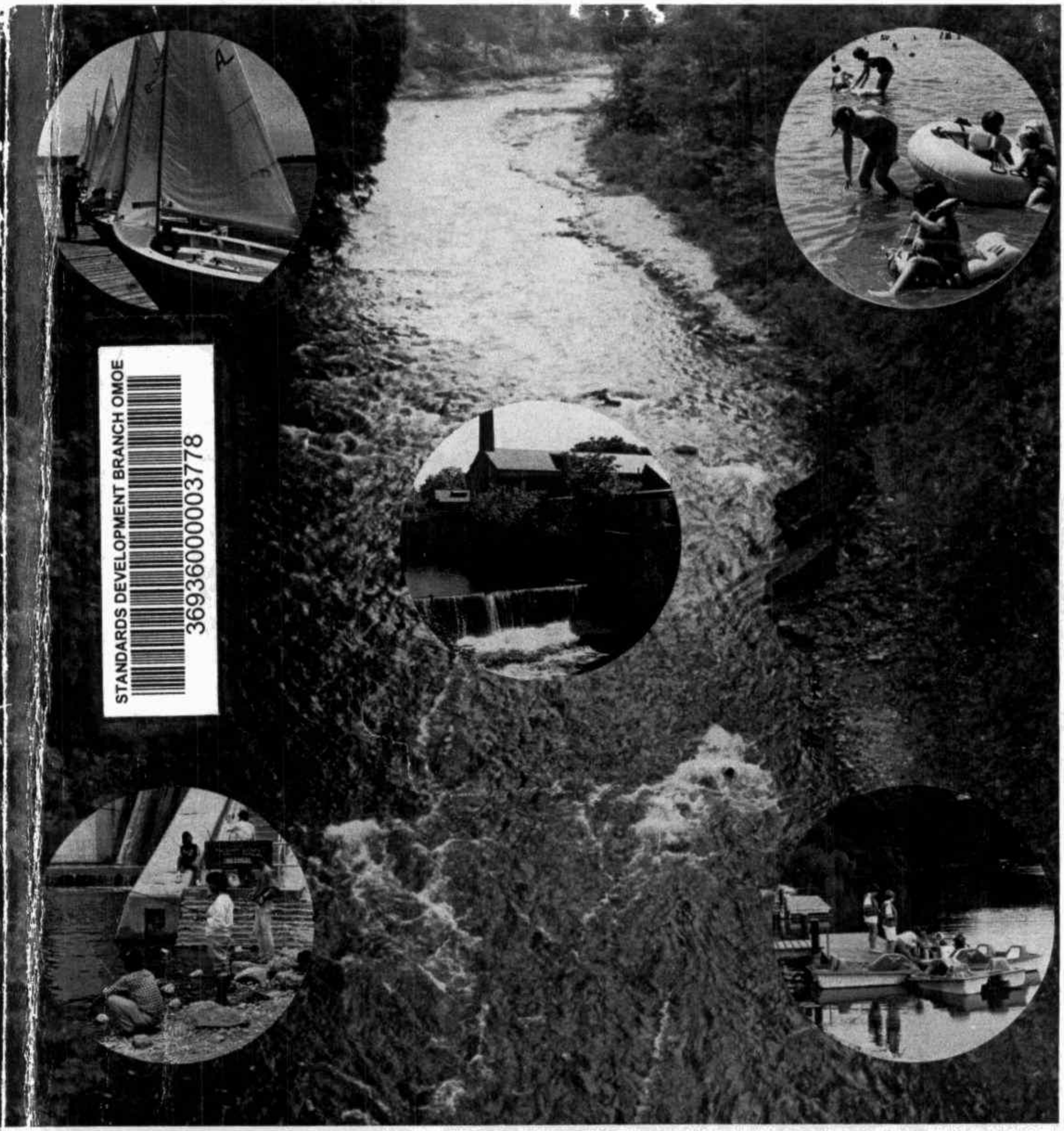

MANAGING ONTARIO'S STREAMS

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MANAGING ONTARIO'S STREAMS

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Generation Of Streamflow

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Definition and Description of Processes

Preamble

Those engaged in the management of streams need to take careful account of the variations with time of flowrate in streams. Knowledge of the hydrological processes that are active in the generation of streamflow is important in the understanding of these flowrate variations. Such knowledge emphasizes the possibility of large variation, suggests what conditions and events give rise to them, and allows some measure of prediction of their future occurrence.

In the first section of this paper physical processes giving rise to streamflow are described. In the second section some of the mathematical techniques used to analyze streamflow are presented.

Generation Processes

An examination of the sources of streamflow is most clearly conducted within the physical unit of a watershed. The boundaries of a watershed are determined by the surface topography and the subsurface stratigraphy of the land around the stream. Each location along the length of a stream defines a different watershed since the lower portion of the watershed boundary moves as the definitional location of the place on the stream to be considered as the outlet is shifted.

For the purpose of this paper a watershed is a specified region of space which has a top, bottom and sides. The top surface of the watershed is the interface between the land surface, including the vegetation on it, and the atmosphere. The intersection between the top surface of the watershed and the sides of the watershed divide. This is further defined below.

The sides of the watershed are vertical planes extending down from the watershed divide into the earth. The bottom of the watershed is an arbitrarily selected surface which is often chosen to follow a geological formation which has little flow of water across it.

The watershed divide is a line on the earth's surface. The watershed divide crosses the top surface of the outlet stream of a watershed perpendicular to the direction of flow at the location which has been chosen to define the watershed. The watershed divide encloses all the land surface upstream of the definitional location on which water could flow toward the specified stream upstream of the definitional location.

The surface area within a watershed divide has the property that if all the depressions in the surface are sufficiently full and if sufficient water is continuously supplied, water will flow from every point in the area to the definitional stream.

The features of a watershed needed to identify the major processes contributing water to streamflow are shown in Figure 1. Some brief comments on the labelled elements follow.

Precipitation - This includes rain and snow and other rarer forms of liquid and solid water falling on the watershed surface. Dew is dealt with as part of evapotranspiration. Snow is active in streamflow generation only after melting except for snow that falls on lake ice and creates a rise in water level that triggers an increase in outflow from the lake.

Evapotranspiration - This is water (rain or snow) held above the ground surface on vegetation. Water which eventually falls from the vegetation to the ground is usually not counted as interception and this term is limited to water that will eventually return to the atmosphere by evapotranspiration.

Depression Storage - This accounts for all water prevented from flowing over the watershed surface by reason of its confinement in a topographic depression. Once the depression is filled with water to above its lowest elevation water flow over the land surface begins in a downslope direction from the depression. Depression storages empty by infiltration and evapotranspiration.

Overland Runoff - This is the movement of water in a downslope direction over the land surface until it enters a recognized stream. The term sheet flow describes the initial part of the overland flow of water. Once flow is occurring in a channel with distinct sides (or banks) it should properly be termed streamflow. Often an arbitrary minimum size is placed on the term "stream" and a significant part of the overland flow path water follows to the "stream" is in a set of parallel channels and not in the form of sheet flow.

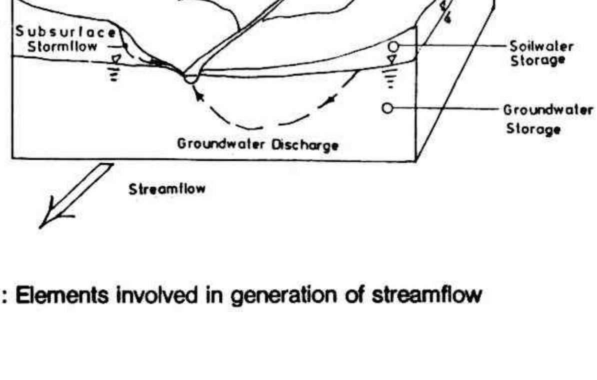

Figure 1: Elements involved in generation of streamflow

Subsurface Stormflow - This is the movement of water downslope to streams below the watershed surface and either above or below the watertable but in regions that only convey water for short periods during and after the occurrence of rain and/or snowmelt. Pathways that allow this process to occur include natural piping passages due to soil cracks, root channels and animal burrowing, and the installation of subsurface drainage in agricultural areas.

Regional Groundwater Discharge - This is the water entering streams from the saturated regional of soil and rock that lies below the watertable of the watershed. Small disconnected saturated pockets that occur intermittently after storms and contribute seepage to streamflow for short periods are treated as contributing to subsurface stormflow.

Infiltration - This is the maximum rate at which water can enter the soil. The infiltrability varies with specified location and is often highly variable in time. Whenever the rate of arrival of liquid water at the soil surface exceeds the infiltrability then superficial (above surface) water begins to accumulate. It first enters depression storage and if enough accumulates to fill all the depressions along a flowpath then overland runoff occurs.

Soilwater Storage - This is the detention or retention of water in the pores of soil or rock under conditions of partial saturation with some of the pore space occupied by air. Some of the water in soilwater storage may be in motion downward under the influence of gravity and this portion is called gravity-water storage. this water contributes eventually to subsurface stormflow or to groundwater storage. The amount of water in soils that is held by capillary or other forces and cannot be moved downward by gravity is called capillary-water storage. It can only be depleted by evapotranspiration.

Groundwater Storage - For this paper this is defined as the amount of water present below the watertable. It is true that soil water is properly considered as a subset of groundwater but it is useful to separate the two parts of the groundwater region, i.e. the unsaturated and the saturated zones, in order to emphasize their different roles in the generation of streamflow.

Properties of Stream Flow Components

The three source components for streamflow - overland runoff, subsurface stormflow and groundwater discharge - have different patterns of distribution in time and different ranges of volume and peak rates. There are not a large number of field studies that have clearly identified and measured all three components separately. Examination of measured hydrographs of streamflow does not allow easy separation of the contribution of each component.

In Figure 2 the results from an interceptor trench on a hillslope are shown (Dunne and Black, 1970a). These reveal the most important attributes of the three flow components. Overland runoff has the highest potential for flow peak since it has no limit on flow depth, velocity increases with flow depth, and flowrate is the product of depth times width times velocity. Subsurface stormflow has an intermediate capability for peak rates. Velocity for this component is bounded but area of flow can vary great-

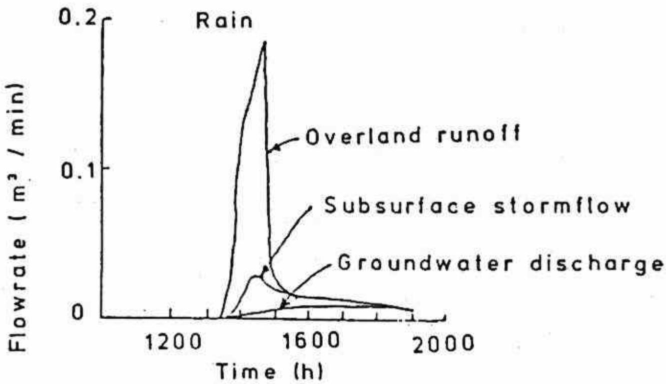

Figure 2: Components of streamflow measured on a hillslope (Dunne and Black 1970a)

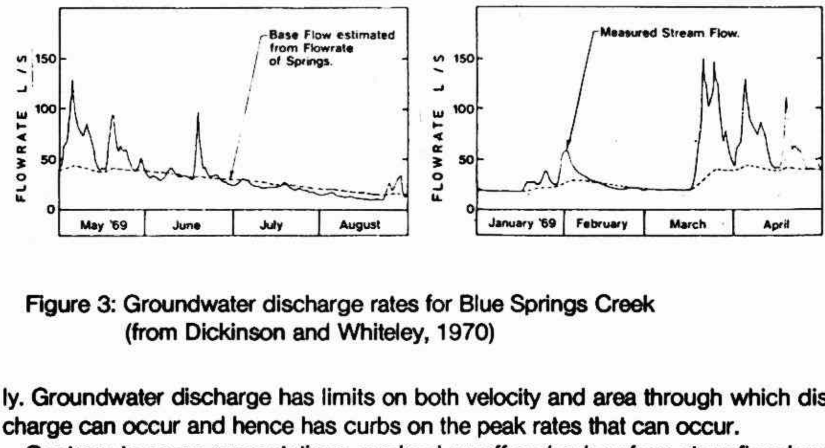

Figure 3: Groundwater discharge rates for Blue Springs Creek (from Dickinson and Whiteley, 1970)

ly. Groundwater discharge has limits on both velocity and area through which discharge can occur and hence has curbs on the peak rates that can occur.

Contrary to some presentations overland runoff and subsurface stormflow have about the same time-to-peak from the time-to-peak rain and/or snowmelt rate. Groundwater discharge has a somewhat delayed peak, especially if bank storage occurs. The more distinct difference is in the recession patterns for the three components. Overland runoff receeds very rapidly, subsurface stormflow has more gradual recession and groundwater discharge has a very gradual recession. Figure 3 shows the pattern of groundwater recession as measured at a spring. The pattern of streamflow closely resembles the spring except for storm periods confirming the groundwater source of baseflow for this stream.

Advances in Identification of Processes Generating Streamflow

It remains true that for many streams there can still be considerable uncertainty over the relative contributions to streamflow from overland runoff, subsurface stormflow, and regional groundwater discharge for a specified storm event. A major

reason for this uncertainty is the lack of information of the three-dimensional spatial variability of the watershed material below the watershed surface. The inhomogeneity of this material, and topographic variations in the surface, greatly alter the infiltrability of the surface from place to place. It is the infiltrability, interacting with rates of rain and snowmelt that vary greatly in space and time, that determine the amounts of overland runoff generated by different areas and the amount of water entering soilwater storage and percolating to the watertable. Given the complexity of the processes involved it is not surprising that much improvement in the quantitative description of streamflow generation remains to be accomplished.

The sources of streamflow during periods that are more than ten days after the end of the last rain or snowmelt are the most certain. Under these circumstances streamflow is clearly coming from storage that depletes slowly. The only storages that have this property are large depressions (lakes or wetlands) or regional groundwater. In southern Ontario natural lakes and wetlands are generally insufficient in areal extent to sustain useful streamflow. Consequently dry period flow (baseflow) comes from groundwater discharge.

During storm events the source of streamflow is strongly dependent on the duration and intensity of the rain and/or snowmelt, on the surface and subsurface properties of the watershed and on initial conditions. Extreme examples range from an urban watershed with a large amount of area with zero infiltrability to a mature forested watershed at the end of an extended dry period. In the first case any rain or snowmelt will cause some overland runoff. Streamflow amounts and timing are largely governed by rain or snowmelt rates. In the second case for small or medium events the only streamflow response will be created by rain or snowmelt falling on or very near perennial stream surfaces. The rest of the watershed surface will have a high infiltrability, all water will enter the soil surface and the water entering will be taken into capillary soilwater storage. There will be no subsurface stormflow created and no water will percolate to the watertable to cause a rise in the watertable and hence a rise in the rate of groundwater discharge to the stream.

For very high intensity rains on the forested watershed some overland runoff can be generated even for a initially dry condition. For events that are both long and of high intensity, or for events with more moderate intensities and durations but that occur under wet initial conditions, all three types of streamflow generation may become active, even on forested watersheds.

The present categorization of runoff generation take account of the spatial variation present on most watersheds. Some potions of some watersheds generate overland runoff from all events. These portions have been termed partial areas (contributing overland runoff to streamflow) as introduced by Betson (1964). Such areas include perennial stream surfaces, wetlands areas connected by channel flow to streams, and areas adjacent to streams that have near zero infiltrability because of low permeability (roads, ditches) or because of the watertable being perennially at or near the land surface. Partial areas are usually considered to be approximately constant in location and surface area.

A second category of surface is the downslope portion of hill slopes where the watertable may rise to the surface during storm events. These surfaces have been termed variable source areas (Dunne and Black, 1970a,b). They differ from the partial areas in their variablitiy in extent and by their contribution of both overland runoff (due to low infiltrability) and subsurface stormflow to streamflow.

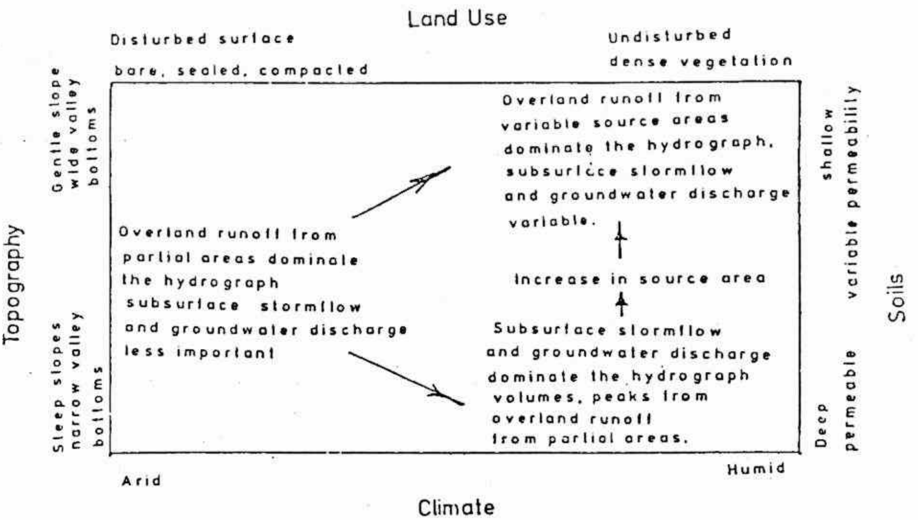

Figure 4: Variarion of streamflow components with topography, soils land use and climate (After Dunne, 1978)

The third category of surface is one where the infiltrability remains relatively high and uninfluenced by the watertable since the latter remains more than say 1 m below the surface. For these surfaces overland runoff will be generated only during periods when rain and/or snowmelt is greater than the infiltrability.

It must be recognized that in addition to overland runoff and subsurface stormflow from these three types of surface the groundwater component of streamflow will also vary during storm events. For streams in incised valleys with a watertable that has significant slope perpendicular to the stream the groundwater recharge to the stream will increase during an event despite the rise in stream water level. This comes about because percolation to the watertable causes a rise in watertable that is greater than the rise in water level in the stream.

In contrast a stream with wide flat plain areas on either side may experience a decrease in groundwater recharge during periods of rapid streamflow and water level rise. This occurs wherever the stream water level rises faster than the surrounding watertable. In some cases the direction of groundwater flow can be reversed in the period up to the time of peak flowrate or even beyond and water from the stream percolates into the bank. This "bank storage" is temporary and as stream water levels rise more slowly, or begin to fall, the flow of groundwater to the stream resumes.

The general pattern of contributions to streamflow under varying circumstances is shown in Figure 4 after Dunne (1978).

At the moment the most significant advances in prediction of what streamflow generation processes are important are in the exploration of better methods of estimating infiltrabilty (Rawls and Brakensiek, 1983) and continued exploration of the

role of the saturated zone in the generation of all three components of streamflow (Freeze, 1974). These advances are gradually being incorporated into deterministic hydrological models that calculate streamflow based on inputs of rain, snow and other meteorological measurements.

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Mathematical Treatment of Runoff

Note: In this section runoff is taken to be overland flow unless otherwise specified.

Runoff is a physical process of water movement, the end result of which we often observe as streamflow. Normally, we relate runoff as measured rate of flow, q, at a given depth, y; frequently described as relationship between discharge and stage (figure 1a):

$$(1)\quad q(t) = q_0 y^n(t)$$

Traditionally, this has been used as the basis to reproduce runoff from stream-depth measurements. The behaviour of the catchment creates storage action (figure 1b):

$$(2)\quad S(t) = S_0 y^m(t)$$

which causes modulation and attenuation to the overland runoff. Under steady-state flow condition the storage can be described as a function of flow; using y from equation (1) gives (figure 1c.):

$$(3)\quad S(t) = f[q(t)] = aq^N(t);$$

$$\text{in which, } S_0[1/q_0]^{m/n} = a, \text{ and } m/n = N$$

Under unsteady-state flow condition, dq(t)/dt, there is further modulation (figure 1d.):

$$(4)\quad S(t) = a_1 q^N(t) + a_2 dq(t)/dt.$$

With regards to the created runoff u(t), the continuity equation under uniform input, states:

$$(5)\quad u(t) - q(t) = dS(t)/dt.$$

It is known that the rainfall input is heterogeneous in nature; therefore, the storage equation becomes:

$$(6) \quad S(t) = a_1 q^N(t) + b_1 u(t)$$

where, $b_1 u(t)$ accounts for the non-uniformity in input to runoff.

Differentiating equation (3) and substitution into equation (5), for the steady-state condition, produces a first-order nonlinear differential equation:

$$(7) \quad aNq^{N-1}(t)dq(t)/_{dt} + q(t) = u(t)$$

and for the steady-state condition with non-uniform runoff input gives:

$$(8) \quad aNq^{N-1}(t)\, dq(t)/_{dt} + q(t) = u(t) - b_1 du(t)/_{dt}$$

Under the unsteady-state condition with uniform input produces a second-order nonlinear differential equation:

$$(9) \quad a_2 \frac{d^2}{dt^2} q(t) + a_1 Nq^{N-1}(t) \frac{d}{dt} q(t) + q(t) = u(t)$$

however, for the unsteady-state condition with non-linear input gives:

$$(10) \quad a_2 d^2 q(t)/dt^2 + a_1 Nq^{N-1}(t)\, dq(t)/_{dt} + q(t) = u(t) - b_1 du(t)/_{dt}.$$

It is known, that the system is time-varying in nature; hence, the second-order differential (equation (10)), becomes:

$$(11) \quad d^2 q(t)/dt^2 + \alpha_1(t)\, dq(t)/_{dt} + \alpha_2(t) q(t) = \beta_o(t) u(t) + \beta_1(t) du(t)/dt$$

where,

$$(11.1)\quad \alpha_1(t) = \frac{a_1(t)}{a_2(t)} N(t)q^{N(t)-1}(t)$$

$$(11.2)\quad \alpha_2(t) = 1/a_2(t) = \beta_o(t)$$

$$(11.3)\quad \beta_1(t) = -\frac{b_1(t)}{a_2(t)},$$

in which the system is nonlinear in the coefficient $\alpha_1(t)$; and $\beta(t)$'s are coefficient on rainfall input.

Equation (11) can be expanded to equate the general order differential equation for a nonlinear, time-varying, single input-output system (Zadeh and Desoer, 1963):

$$(12)\quad \frac{d^n}{dt^n}q(t) + \alpha_1(t)\frac{d^{n-1}}{dt^{n-1}}q(t) + \ldots + \alpha_n(t)q(t)$$

$$= \beta_o(t)\frac{d^n}{dt^n}u(t) + \beta_1(t)\frac{d^{n-1}}{dt^{n-1}}u(t) + \ldots + \beta_n(t)u(t)$$

Equation (12) has been the basis upon which earlier developments in runoff production were carried out by Nash (1957), Dooge (1959), and Prasad (1967), Singh (1964), Kulandaiswamy (1964).

Analytical Solution

For simplicity, we may consider equation (12) as linear and time-invariant; then for a zero initial condition, the solution by convolution (Zadeh and Desoer, 1963):

$$(13)\quad q(t) = \int_{t_o}^{t} h(t,\tau)u(\tau)d\tau$$

where, $h(t, \tau)$ is the impulse response function which characterized the system. This is defined as an input of unit magnitude, but of very short duration. The determination of $h(t, \tau)$ relates to identification, for example, the instantaneous unit Hydrograph (IUH); which is demonstrated, as follows using linear storage reservoir and channel; and later by the kinematic wave equations.

Linear Reservoir and Channel

We can review how the catchment transfer excess rainfall to runoff by examining the storage function described by a linear steady-state, first -order and time-invariant system. Consider equation (7), N = 1, and a unit step input:

$$u(t)/_a = \left[\begin{array}{l} 0,\ t < o \\ 1,\ t \geq o \end{array}\right.$$

from which the total solution by convolution gives:

$$(14)\quad q(t) = c_1.e^{-t/a} + c_2$$

It should be noted that $q(t) = a$, $t \rightarrow \infty$, such that $c_2 = a$,

and, the unit step response function becomes:

$$(15) \quad q(t) = c_1 . e^{-t/a} + a.$$

It follows subsequently that the impulse response function for the single linear reservoir is:

$$(16) \quad h(t) = dq(t)/_{dt} = -(c_{1}/_{a}) .e^{-t/a}$$

With the use of an instantaneous input of volume, , the conservation of mass gives:

$$(17) \quad \int_{t_0}^{\infty} h(t)dt = U_o = \int_{t_0}^{\infty} -(c_1/a).e^{-t/a}\, dt = -c_1$$

Hence, the response or outflow is an exponential decay from a value of U_o:

$$(18) \quad h(t) = (U_o/a)\, e^{-t/a},$$

indicating therefore that the unit impulse response is non-zero only for positive value of the argument.

The translation of the runoff can be handled by the concept of linear channel (Dooge,1959). In this case, the linear channel ensures no change in the shape of the input wave due to the constant disturbance velocity at all stages.

Consider a channel area, A, and an average velocity V, with:

$$(19) \quad A = q/\overline{V},$$

the continuity equation:

$$\partial q(t)/\partial x + \partial A/\partial t = 0$$

with equation (19) gives:

$$\partial q(t)/_{\partial x} + 1/_{V}\, \partial q(t)/_{\partial t} = 0$$

The solution is the runoff lagged by τ:

$$(20) \quad q(t-\tau) = \text{constant}$$

It should be noted that this impulse is only a translation; and is equal to the wave travel time. The combination, in series, of the linear reservoir and linear channel is shown diagrammatically in figure 2a, with impulse response (figure 2b) given as:

$$(21) \quad h(t) = (U_o/a)\, e^{-(t-\tau)/a}, t > \tau$$

Maddaus and Eagleson (1969) consider a cascade of linear reservoir using differing time-varying lateral inputs. this was used to derive runoff as a summation of separate solutions of equation (7):

$$(22) \quad q_{sum} = \sum_j h_j(t).u_j(t)$$

the components for the unit impulse response of equation (22) are:

$$h_1(t) = \frac{e^{-t/a}}{a}$$

$$h_2(t) = \frac{e^{-t/a}}{a1!}(t/a)$$

$$\vdots$$

$$(23) \quad h_n(t) = \frac{e^{-t/a}}{a\Gamma(n)}[t/a]^{n-1},$$

which are the elements of the Nash (1957) representation.

The distributed channel and reservoir runoff representations as an expansion of equation (23), were derived by Maddaus and Eagleson (1969). Figure 2c describes this distributed system. The unit impulse response function for the combined linear reservoir and linear channel is:

$$(24) \quad H(t) = \frac{1}{N}\sum_n^N \frac{e^{-(t-n\tau)/a}}{a\Gamma(n)} . \frac{(t-n\tau)}{a}, n-1, t > n\tau$$

Runoff is characterized by its impulse response function. That is, the objective in application is to determine the unit impulse response. Schulz et al (1971) developed functions for the dimensionless IUH. Typical applications on catchments are shown in figure 3. Historically, a number of factors have been described in relating IUH to physical characteristics of the catchment. For example, the time of

ment and the length of the catchment were observed to be related to the IUH parameters. This led to investigation by Wooding, (1965) who utilized the Kinematic Wave theory to develop the IUH.

Kinematic Wave

Excess rainfall and snowmelt exceeding infiltration fill the depression storages. Runoff follows subsequently as soon as the gravitational forces exceed surface irregularities and surface tension. A number of small channel flows combine to form total runoff. Wooding (1965) consider the catchment stream geometry (figure 4.1) in which the parameters which dominate runoff from the catchment and stream are slope, roughness; and flow regime. In this case, runoff is modelled by considering the equations of motion as applied to the control volume of direct runoff (figure 4.2).

The momentum equation in this case is:

$$(25)\quad \frac{\partial V}{\partial t} + V\frac{\partial V}{\partial x} = g(S - \frac{\partial y}{\partial x}) - \frac{\tau_o}{pR}$$

Where, V is velocity of flow; S is slope of the catchment; g is the gravitational constant; y is depth of flow, t_o is the time constant of channel area (A); R is the hydraulic radius; p is the fluid mass density; and x and t are space and time variables.

Similarly, the continuity equation:

$$(26)\quad \frac{\partial(AV)}{\alpha x} + \frac{\alpha A}{\partial t} = q_L + Bu$$

Where, q_L is the lateral inflow due to surface runoff; B is the channel width; and u is the rainfall excess.

Application of this approach requires consideration of runoff production under, either, laminar or turbulent flow conditions. The experimental Reynolds and Mannings equation can be used to relate the kinematic equations to the physical parameters. Under steady-state and uniform flow the momentum equation reduces to:

$$(27)\quad q = Vy = \alpha_C y^{m_C} ;$$

where, (using Reynolds formula):

$$\alpha_C = (2.g\ S/C_f)^{1/2} \text{ and } m_C = 2/3$$

in which C_f is the friction coefficient of Reynolds number. For turbulent flow condition, and with the use of Mannings formula.

$$(28)\quad q = Vy = (f/n)A.R^{2/3}\,S^{1/2} = \alpha_C\, y^{m_C}$$

where,

$$\alpha_C = (f/n)\,S^{1/2} \text{ and } m_C = 5/3\,,$$

in which, n is Mannings roughness; and f=1 in SI unit or 1.49 in Br. unit.

With the relationship for these basic parameters, one can now apply the kinematic wave concept arising from the momentum equation (27) or (28); and for small depth in flow, y, the continuity equation:

$$(29)\quad \frac{\partial}{\partial x}(Vy) + \frac{\partial y}{\partial t} = u$$

If it is assumed that α_C and m_C are time-invariant then the kinematic wave equations (27) and (29) lead to the characteristic equations (Henderson and Wooding, 1964):

$$(30)\quad \frac{dx}{dt} = \alpha_C\, m_C\, y^{m_C-1} = C$$

$$(31)\quad \frac{dq}{dx} = \frac{dy}{dt} = u$$

where, C is the wave speed; and similarly, they obtain the path of the wave propagation by integrating equation (30) and (31):

$$(32)\quad x - x_0 = L_C = \alpha_C m_C \int_{t_0}^{t} \left(\int_{t_0}^{t} u(\sigma)d\sigma + y_0\right)^{m_C-1} dt$$

The impulse response function from the characteristic equation (32) can be determined by considering a constant rainfall input, u, of short duration; hence runoff is described as (Maddaus and Eagleson, 1967):

$$(33)\quad q = \alpha_C y^{m_C};\ \begin{cases} y = u.t & ;\ 0 \leq t \leq t_r < t_c \\ y = u.t_r & ;\ t_r < t < t_p \end{cases}$$

$$L_C = \alpha_C y^{m_C-1}\left(yu^{-1} + m_C(t-t_r)\right)\ ;\ t > t_p$$

where, t_p is time to peak, given as:

$$t_p = t_r + (t'_c - t_r) / m_c$$

in which

$$t'_c = L_c / \alpha_c d^{m_c - 1}$$

with

$$d = u.t_r$$

Actually, the impulse response function is obtained from the pulse response function; that is, in the limit as t_r ---> , the discharge begins immediately and remains constant at peak q_p:

$$(34) \quad q_p = \alpha_c d^{m_c},$$

The recession curve of the IUH during period, $t>t_p$ is:

$$(35) \quad q = \alpha_c y^{m_c} = \alpha_c \, [L_c/(\alpha_c m_c t)]^{m_c/(m_c-1)}$$

Figure 5 displays the kinematic wave unit impulse and pulse response functions. Maddus and Eagleson (1967) showed application of the kinematic wave relation to catchment, considering application of the storm near to catchment mouth as compared to the most distant portion of the basin (figure 6).

Numerical Solution

Runoff can be derived through numerical solution of the nonlinear, time-invariant second-order differential equation (10). Dividing by $D^2 \equiv (d/dt)^2$ and rearranging:

$$(36) \quad q(t) = \beta_0 u(t) + \frac{1}{D} [\beta_1 u(t) - \alpha_1 q(t)] + \frac{1}{D^2} [\beta_2 u(t) - \alpha_2 q(t)]$$

where α and β are defined previously. The numerical solution by the finite difference scheme follows:

$$(37) \quad q(j+1) = [u(j+1) - \frac{b_1}{\Delta t}(u(j+1)-u(j)) - q(j)(1 - \frac{2a_2}{\Delta t^2}$$
$$- q(j-1)(\frac{a_2}{\Delta t^2} - \frac{a_1}{2\Delta t} Nq^{N-1}(j))] [\frac{a_2}{\Delta t^2} + \frac{a_1}{2\Delta t} Nq^{N-1}(j)]^{-1}$$

where, j denotes the time-stage; and Δt the time increment.

In application, the solution follows a trial-and-error approach (Prasad, 1967) or a gradient pattern search approach (Logan, 1979), in which an objective function,

$J[e(\pi)]$,subject to the given parameters, is minimized:

$$(38) \quad J[\hat{e}(\pi)] = \hat{e}^2(\pi) = \sum_{t=1}^{n} [q(t)-\hat{q}(t)]^2$$

where, $\hat{e}(\pi)$ denotes the residual error, q(t) and q(t) denote the observed and computed flow, respectively.

Figure 7 shows typical examples of runoff production using this approach.

Similarly, runoff can be produced by considering the nonlinear time-varying second-order differential equation (11). The parameter identification in this case is based on the use of the iterative least-square estimation of the Marquardt technique:

$$(39) \quad J[e(\pi)] = \sum_{t=1}^{m} \left[\hat{e}_t(\pi) - \sum_{i=1}^{n} \frac{\partial}{\partial \pi_i} \hat{e}_{t,\ i}(\pi) \Delta\pi_i \right]^2$$

where, the objective function, $J[e(\pi)]$, is minimized with respect to the perturbation of elements of the parameter vector over each time horizon; and the residual error vector, $\hat{e}_t\ (\pi)$ is:

$$(40) \quad \hat{e}_t(\pi) = q_t - \frac{1}{n} \sum_{i=1}^{n} \hat{q}_{t,\ i}(\pi)$$

Here, q_t is the observed flow is each time horizon and $\hat{q}_{t,\ i}(\pi)$ is the estimated outflow in each time period, assuming nominal values for the vector parameters π . The $\Delta\pi_i$ is the improvement desired in each parameter value in order to minimize the objective function. The summation of the squared errors is carried over m-time horizons, each divided into n- time periods. Each parameter is optimized iteratively, in turn;

$$(41) \quad \pi_{t,\ i}(k) = \pi_{t,\ i}\ (k-1) + \Delta\pi_{t,\ i}\ (k)$$

Runoff using this approach is shown in figure 8.1; and the corresponding propagation of the time-varying parameters in figure 8.2.

An effective use of the time-varying runoff production is for forecasting as required for hydropower or flood mitigation. A comparison showing time-invariant and time-varying runoff production is shown in figure 8.3.

Kalman Filter Runoff Prediction

It is known that there are uncertainties imbedded in the measurement of rainfall input and runoff output; and also in the model used to describe the processes. Duong (1972) and Logan (1970) utilized the state-space concept to describe the dynamic and measurement processed for runoff production, in which the Kalman filter es-

timation technique is used in analysis under the condition of white noises.

For example, we may consider the nonlinear, time-varying second-order differential equation (11) in runoff production; from which we can define the state vector, $\underline{X}(t)$, of the stem as:

$$(42) \quad \underline{X}(t) = [X_1(t)\ ,\ X_2(t)\ ,\ X_3(t)\ ,\ X_4(t)]$$

where,

$$q(t) = X_1(t)$$

$$dq(t)/_{dt} = X_2(t)$$

$$a_1(t)\ N(t)q^{N(t)-1}(t) = X_3(t)$$

$$^1/_{a_2(t)} = X_4(t)$$

From which we can define the dynamic process as:

$$(43) \quad d\underline{X}(t)/_{dt} = F(\underline{X}(t), \underline{U}(t), t)$$

where,

$$F[\underline{X}(t), U(t), t] = \begin{bmatrix} X_2(t) \\ -X_4(t)X_3(t)X_2(t) - X_4(t)[X_1(t) - u(t) + b_1(t)\dfrac{du(t)}{dt}] \\ (N(t)-1)X_1^{-1}(t)X_2(t)X_3(t) \\ 0 \end{bmatrix}$$

Similarly, the corresponding observation model as:

$$(44) \quad Z(t) = H[\underline{X}(t), \underline{U}(t), t]$$

where, $\underline{Z}(t)$ is the observation vector.

Because of the nonlinearity in equations (43) and (44), the application of this ap-

proach requires linearization. The iterated Kalman filter technique is used in this case; hence the linearized dynamic process model becomes:

$$(45)\quad \frac{d\Delta Xt}{dt} = F'(t)\Delta \underline{X}(t) + G(t)\underline{W}(t)$$

and the linearized measurement model:

$$(46)\quad \Delta \underline{Z}(t) = H'(t)\Delta \underline{Z}(t) + \underline{V}(t)$$

where,

$$(47)\quad F'(t) = \frac{\partial}{\partial \underline{X}(t)} F[\underline{X}(t), \underline{U}(t),t] = \begin{bmatrix} 0 & 1 & 0 & 0 \\ B_1 & B_2 & B_3 & B_4 \\ E_1 & E_2 & E_3 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

and

$$(48)\quad H'(t) = \frac{\partial}{\partial X(t)} H^T[\underline{X}(t),U(t),t] = [1, 0, 0, 0]$$

in which the elements of F'[t] are defined as:

$$B_1 = -X_4(t)$$

$$B_2 = X_4(t)X_3(t)$$

$$B_3 = -X_4(t)X_2(t)$$

$$B_4 = X_3(t)X_2(t) - [X_1(t) - u(t) + b_1(t)\frac{d}{dt}u(t)]$$

$$E_1 = -(N(t)-1)X_1^{-2}(t)X_2(t)X_3(t)$$

$$E_2 = (N(t)-1)X_1^{-1}(t)X_3(t)$$

$$E_3 = (N(t)-1)X_1^{-1}(t)X_2(t)$$

The solution procedure requires an initial value of the linearized vector $\Delta\hat{\underline{X}}(t)$:

$$\Delta\hat{\underline{X}}(t_0) = E[\Delta\hat{\underline{X}}(t_0)] = 0$$

Similarly, the linearized process and measurement models are driven by the white noises, $\underline{W}(t) = N[0, Q(t)]$, and $\underline{V}(t) = N[0, R(t)]$, respectively.

F'(t) and H'(t) are the linearization state coefficient matrices and we need nominal values for the process noise variance, $Q(t_0)$ and the measurement noise variances, $R(t_0)$.

The best estimate of $\Delta\hat{\underline{X}}(t)$: can now be determined from the linearized dynamic estimation equation:

$$(49) \quad \frac{d}{dt}\Delta\hat{\underline{X}}(t) = F^1(t)\Delta\hat{\underline{X}}(t)\Delta t + K(t)\,[\Delta\hat{\underline{Z}}(t) - H'(t)\Delta\hat{\underline{X}}(t)\Delta t]$$

where, $\frac{d}{dt}\Delta\hat{\underline{X}}(t)$ and Δt denote time-discrete changes in $\Delta\hat{\underline{X}}(t)$ and t, respectively; K(t) is the Kalman gain.

Similarly, the best estimate for changes in $\Delta\hat{\underline{Z}}(t)$ is

$$(50) \quad \Delta\hat{\underline{Z}}(t) = \underline{Z}(t) - H'(t)\hat{\underline{X}}(t).$$

$$\text{in which, } \hat{\underline{X}}(t) = \underline{X}(t) + \Delta\hat{\underline{X}}(t)$$

The solution of the problem requires an optimal Kalman gain, K(t):

$$(51) \quad K(t) = P(t)\,H'^T(t)\,R^{-1}(t)$$

where, P(t) is the estimation error-covariance.

In the estimation process the Riccati technique is used in the determination of the optimal Kalman gain, K(t). In addition, the optimal measurement noise, R(t), is determined through a variance optimization approach (Logan, 1979). Figure 9.1 shows example of the runoff production using the state space concept and Kalman filter prediction; while, figures 9.2 to 9.3 show the optimal Kalman gain and the error-covariance estimate for the runoff production; and figure 9.4 shows the propagation of the state variables

LANDUSE EFFECTS ON RUNOFF

Natural changes in the catchment affect the magnitude of runoff event. Man-made changes on landuse, however, have the greatest effect on runoff, and subsequently, impact on quality. Hydrologists are particulary concerned with landuse alternatives that affect the hydrologic functioning of the catchment; for example, urbanization

tends to have the greatest effect in increasing peak flows and having short-term impacts on water quality.

In particular, increase in runoff from a given series of storms, in the presence of soil that is impervious, creates moisture reduction to groundwater, and subsequently reduction in baseflow. Unfortunately, the high flows enhances sediment removals. It is known that sediment removal from urban areas tends to be larger that from rural areas. A major concern in high flows in urban areas is the likely introduction of sewage overflow, thereby causing an increase in contamination of nutrients and other pollutants. High levels of nutrients may promote growth of algae and plankton, which may affect the balance of stream biota.

Agricultural developments, particulary certain practices, such as tile drainage, may increase runoff volume in storm events, normally by enhancing water removal through seepage, to the extent that there will be reduction in moisture movement to groundwater and later causing low baseflow. Some agricultural practices such as tillage may increase sediments loss from watershed during high flows. This may result with increase in nutrients, both obtained from loss in agricultural fertilizer and other from excretion products from livestocks.

A serious influence of landuse change in relation to runoff, is the effect on the amenity at from examining the surroundings of the river and channel.For example, high runoff over several occurrences, gradually enlarges the channel; resulting with unstable and non-vegetative banks, causes scoured or muddy channel beds, and unusual accumulation of debris and rubbish. Hydrologists and planners are particularly concerned with the change in frequencies and magnitude of runoff production, brought about by continuing changes in landuse.

RUNOFF USES AND RISKS

Planning and development in water resources demand attention to runoff. Presently, runoff is used extensively to manage environmental problems. It should be noted that runoff provides water for industrial and domestic supplies, serves recreation and fishing industries; and is imperative to navigation, hydroelectric power generation, to farmers for irrigation and to municipalities and industries for wastewater assimilation. Runoff data can serve international purposes, for example, the equitable sharing of flows, such as the Niagara Diversion Agreement between U.S.A. and Canada.

As indicated, runoff is provided as discharge data, or as stage as water level information. The former data are essential to design of dam or reservoir, and are necessary for diversion. Water level data, on the other hand, are important to establish dykes, and to protect river bank and shoreline erosions. Similarly, it is useful to lumber companies, and real estate. In particular, Insurance companies require water level information to assertain the likelihood of flood damage. Runoff depth and velocity are often used as design information for culvert, bridge and abutments.

One should consider the factors that governed flow stages. These relate to the volume of runoff which depends on the precipitation input, the extent and pattern of snowmelt and antecedent soil conditions; and groundwater replenishment.

Runoff production using the methods outlined earlier depends on availability of excess rainfall. During summer period, of low rainfall input; runoff is primarily baseflow from groundwater storages. During this period, runoff gradually depletes the seasonal reserves of water storages. It is therefore necessary to understand the

pattern of behaviour of the runoff (streamflow) during low flow periods. This is important for low flow forecasting as it relates to wastewater assimilation, irrigation and for navigation.

With regards to forecasting, it is assumed that there is a linear relationship between runoff and storage, in this case the rate of depletion of groundwater storage is :

$$(52) \quad q(t) = [q(t_o) - q_g]e^{-kt} + q_g$$

where, $q(t)$ is the flow; $q(t_o)$ is the initial flow, q_g is deep groundwater seepage; k is a constant representing the rate at which groundwater is depleted.

Based on equation (52), there is a linear relation between average flows, , , and in two successive periods of equal duration, T.

Hence,

$$(53) \quad \bar{q}_2(T) = a\bar{q}_1(T) + (1-a)q_g$$

where,

$$a = e^{-kt}$$

using the assumption of linear relationship between average flows, one can determine k and q_g;

note regression relationship:

$$(54) \quad \bar{q}_2(T) = a\ \bar{q}_1(T) + b$$

$$\text{in which } k = \ln a/_T$$

$$\text{and } q_g = b/_{(1-a)}$$

It should be noted that the minimum rate of baseflow, q_g, varies form one year to the next. This is due to the seasonal variation of groundwater fluctuations. Investigation indicated that during recession period low flow can be forecasted by the exponential function:

$$(55) \quad q(t) = q(t_o)\ k^{-at^n}$$

Where, n is a constant varying form 0.5 to 1.5.

In forecast, or for other management uses, there are risks involved in the use of runoff. For extreme runoff events risks are established by extreme probability analysis. Risk in this case is the probability that one or more events will equal or exceed, in terms of severity, the given extreme value, within a specified period of time. The frequency curves of observed events are normally accepted as guide for an estimate of risk for a selected period.

For simplicity, the reciprocal of the recurrence interval, T_R, defines the risk. T_R in this case is:

$$(56) \quad T_R = 1/P(x)$$

where, P(x) is the probability of ranked values according to decreasing order of severity; defined as:

$$(57) \quad P(x) = M/(N+1)$$

in which M is the rank and N is the number of variables.

From the density function for the third asymptotic distribution, one can describe the probability distribution for low flows:

$$(58) \quad P(x) = 1-e^{-y}$$

$$\text{where } y = \left[\frac{x - \varepsilon}{x_o - \varepsilon} \right]^{\alpha}$$

in which x is the variable, x_o , is the characteristic flow, e, is the boundary value and is the scale parameter; and for the high flows, the double exponential distribution is used.

$$(59) \quad P(x) = e^{-e^{-y}}$$

$$\text{where, } y = \alpha(x-\bar{\beta})$$

in which, x is the peak flow, $\bar{\beta}$ is the location of the central value; and α is the scale parameter. In application, one normally consider, as part of the risk, the rare event that will occur during the life-time of the project. Knowledge of risks are essential to mitigate flooding, and to minimize failures in water quality during drought periods.

Typical frequency curves for high and low flow event are shown in figures 10.1

and 10.2.

CONCLUSION

Methods for producing runoff have been described. These include single input-output differential equations, developed using storage function derived from discharge-stage and storage-stage relationships and the continuity equation. It has been cited that many of the earlier works describing runoff were centred about this basic input-output differential equation. Typical analytical solution as to how the differential equation is used in runoff production was described. This led to the basic concept of Instantaneous Unit Hydrograph. To resolve the problem of associating the IUH with catchment parameters, required the introduction of the kinematic wave approach. This added more physical parameters into the relationship in relating to the IUH.

Numerical solution of the single input-output differential equation was described taking advantage of the capability of computers. This numerical technique encouraged expansions in the approach to runoff production. On this basis the state-space concept and the Kalman filtering technique were employed while considering that the runoff and input and system described for runoff production are embedded with noise terms; and are time-varying.

The single input-output relationship looked at direct runoff production. To accommodate continuous flow, even during the time when no input is available, required the introduction of a conceptual watershed model.

Management activities, such as landuse changes affect runoff production. A number of cause-effect relations were described. Management not only influence the system, but utilized the runoff events for a number of beneficial uses. Several uses were described in addition to the risks that are inherent in the use of runoff data for management purposes.

FIGURE 1: STORAGE FUNCTIONS

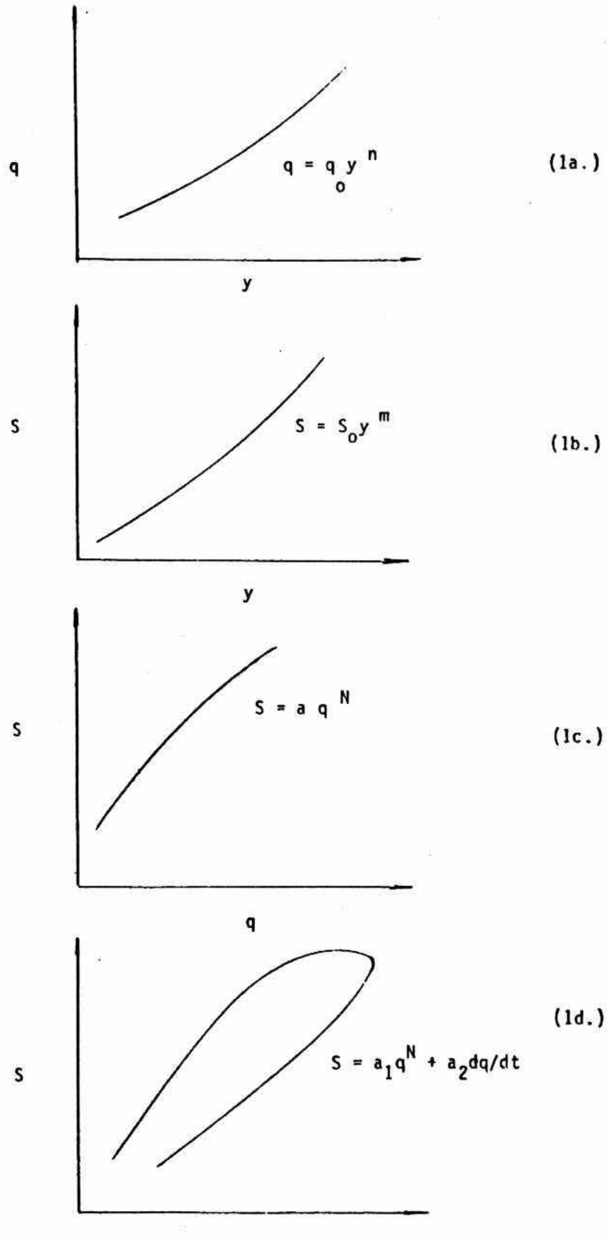


FIGURE 2A: SERIES OF LINEAR RESERVOIR AND LINEAR CHANNEL

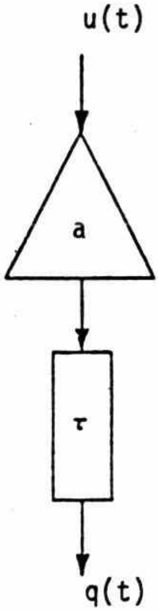


FIGURE 2B: IMPULSE RESPONSE FUNCTION -- SINGLE LINEAR RESERVOIR AND LINEAR CHANNEL IN SERIES

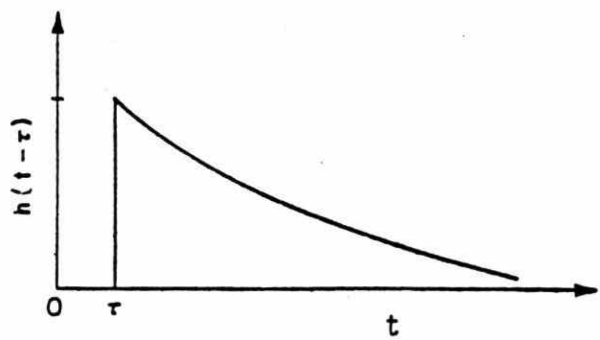


FIGURE 2C: DISTRIBUTED LINEAR RESERVOIR AND CHANNEL IN SERIES

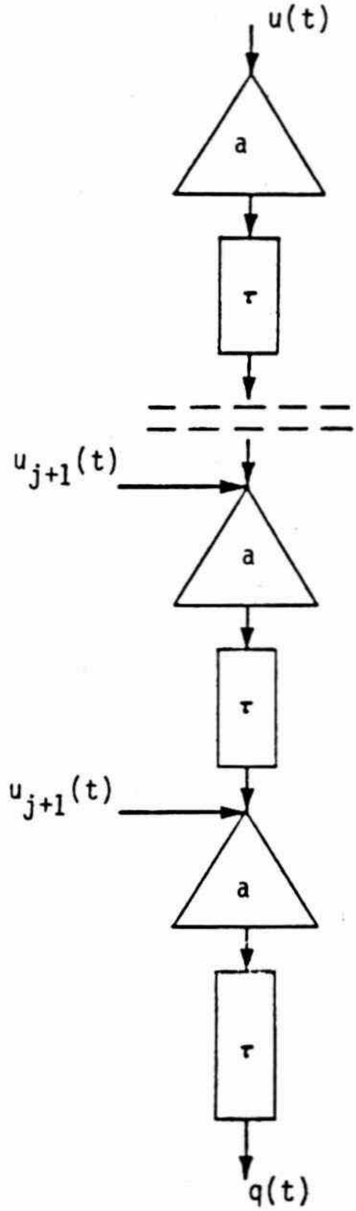
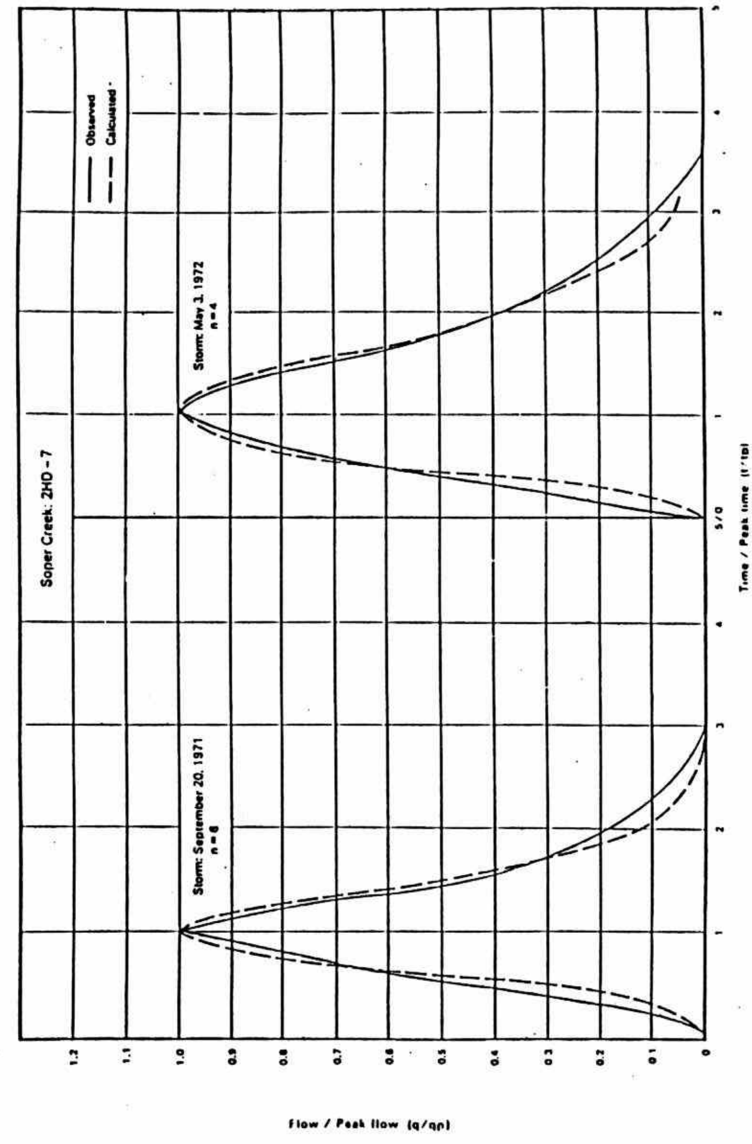


FIGURE 3: DIMENSIONLESS INSTANTANEOUS UNIT HYDROGRAPH



Dimensionless Instantaneous Unit Hydrograph: Soper Creek Basin (2HD-7).

FIGURE 4.1: CATCHMENT-STREAM GEOMETRY

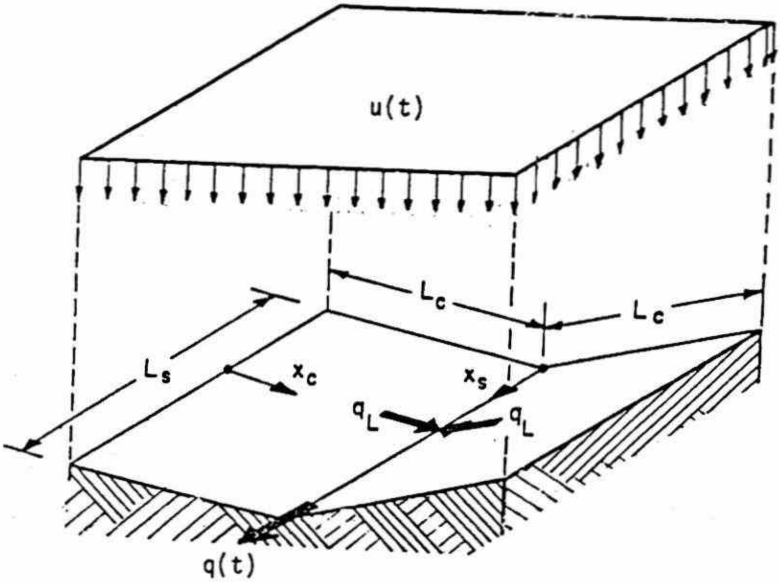


FIGURE 4.2 CONTROL VOLUME OF DIRECT RUNOFF

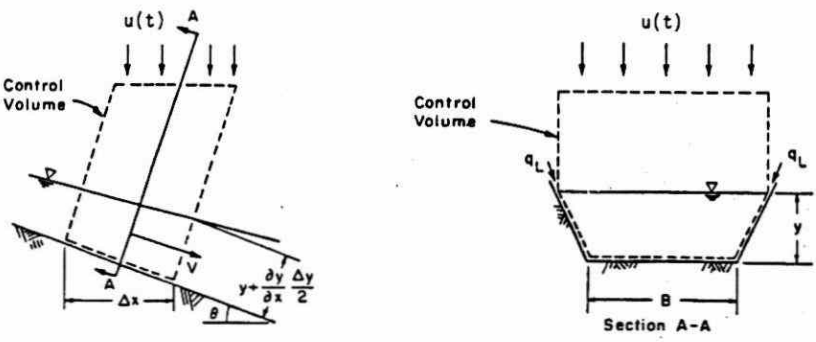


FIGURE 5: KINEMATIC WAVE IMPULSE AND PULSE RESPONSE FUNCTIONS -- (AFTER WOODING)

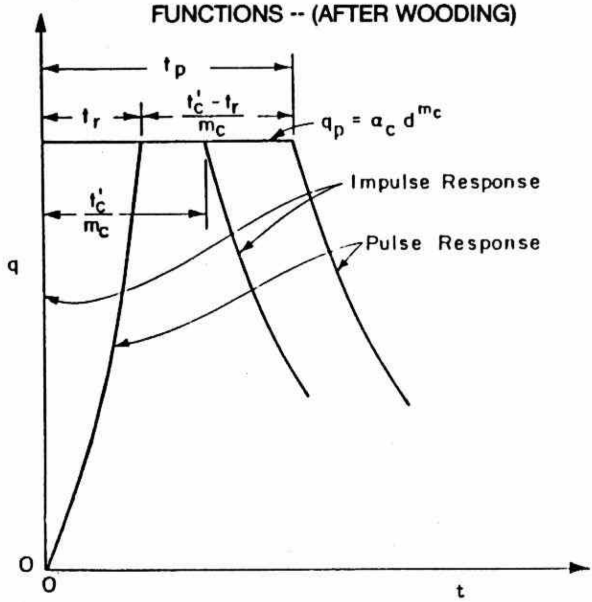


FIGURE 6: COMPARISON OF RESPONSES (RUNOFF) FROM EQUAL LATERAL INPUTS -- (AFTER MADDAUS AND EAGLESON)

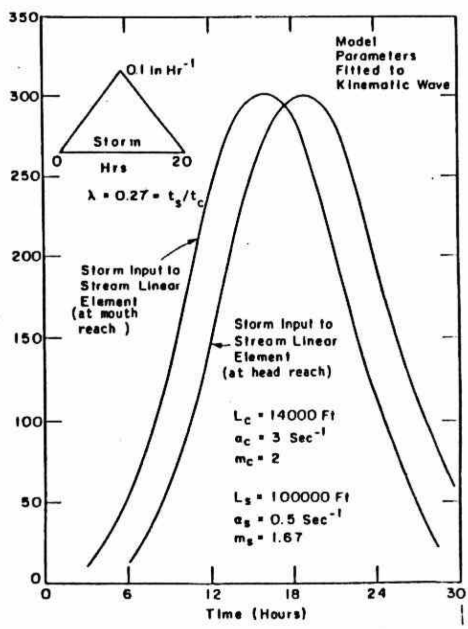
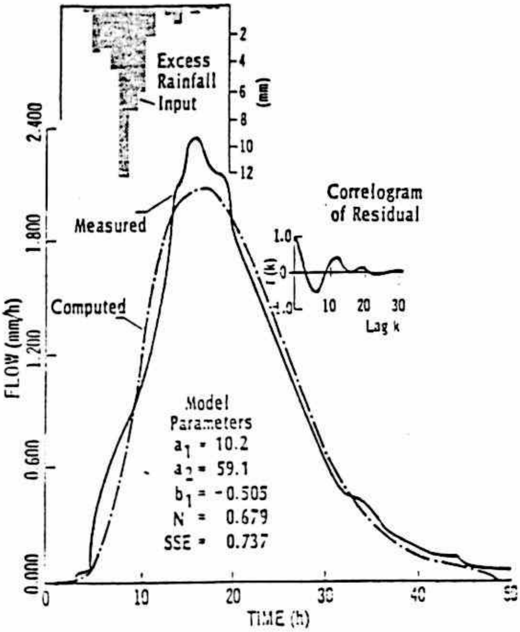
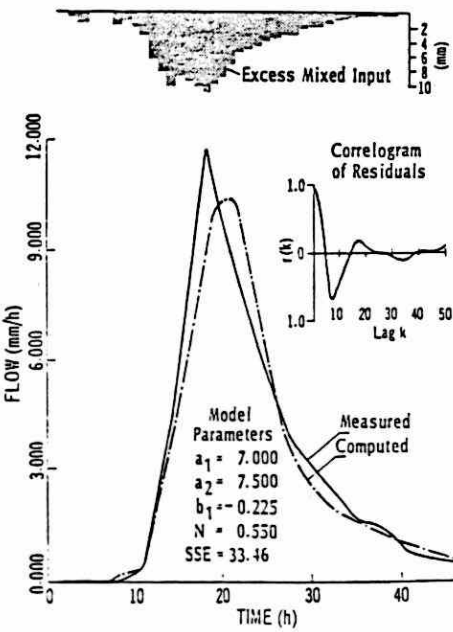


FIGURE 7: RUNOFF PRODUCTION WITH TIME-INVARIANT PARAMETERS

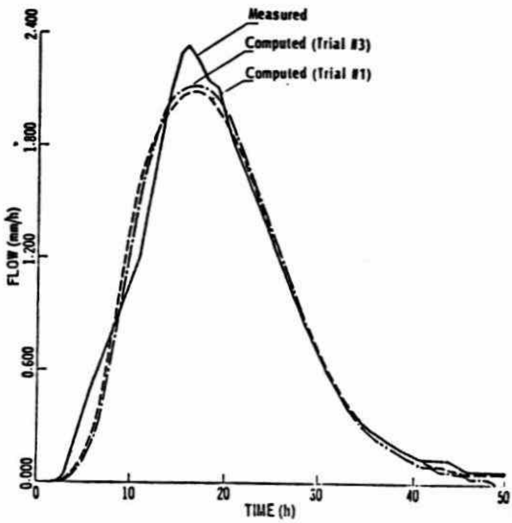


(Nith/Nithburg,23/8/75)

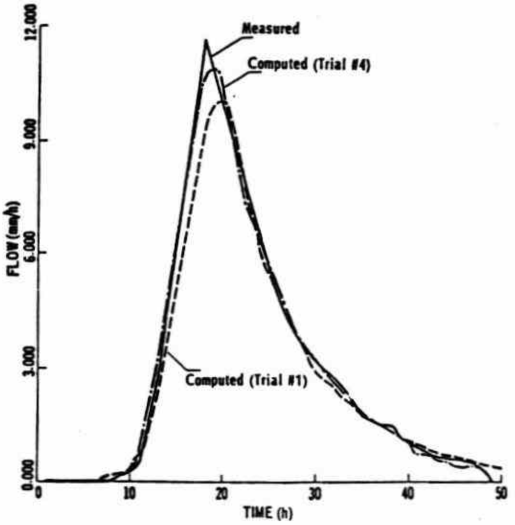


(Grand/West Montrose,16/5/74)

FIGURE 8.1: RUNOFF PRODUCTION WITH TIME-VARYING PARAMETERS

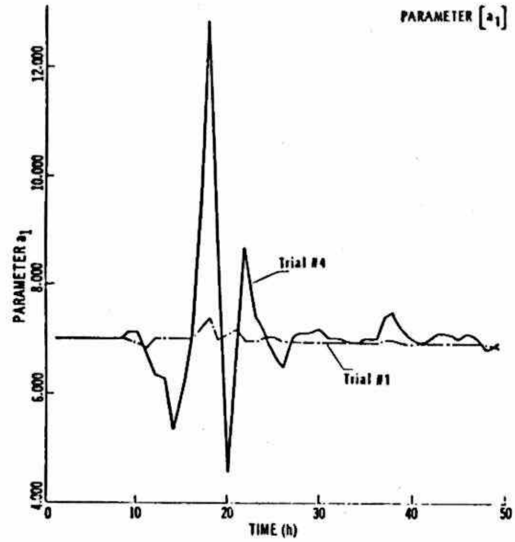


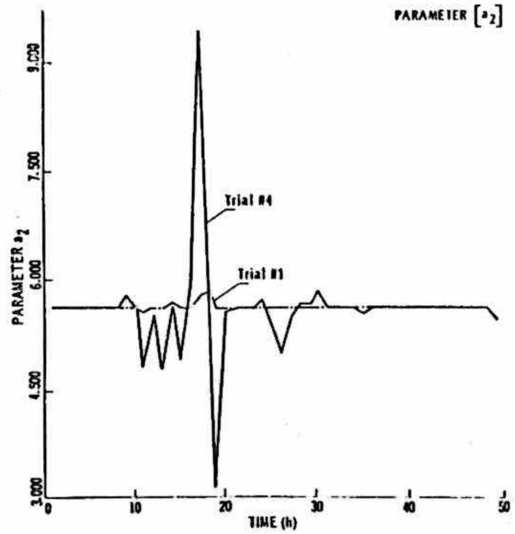
(Nith/Nithburg,23/8/75)



(Grand/West Montrose,16/5/74)

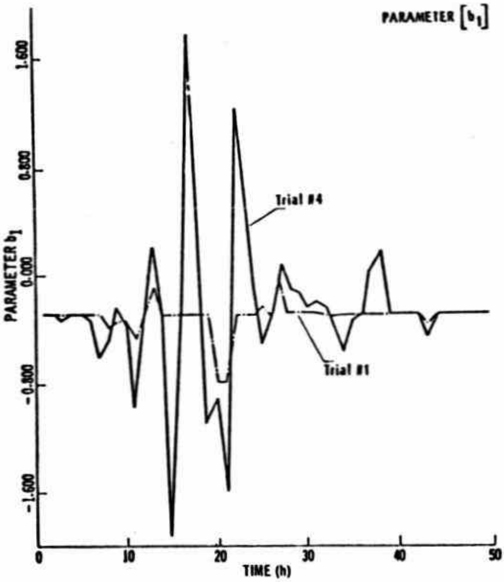
FIGURE 8.2 - (1/2): TIME VARYING PARAMETERS -- RUNOFF PRODUCTION

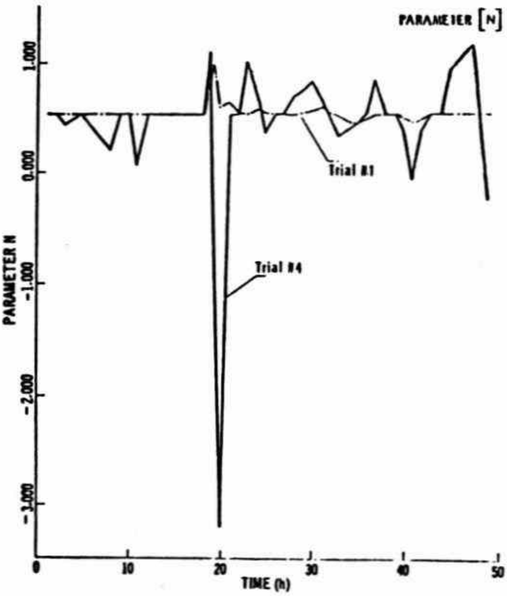




(Grand/West Montrose,16/5/74)

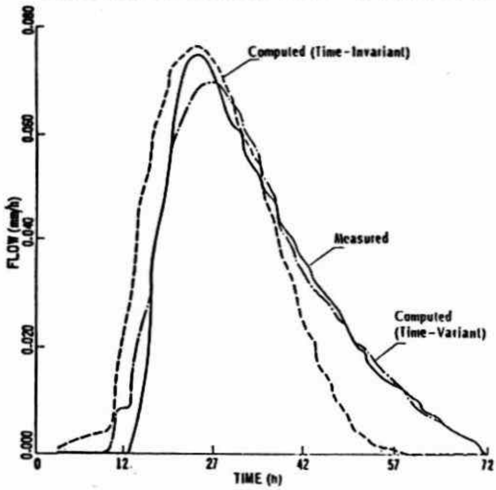
FIGURE 8.2 - (2/2): TIME VARYING PARAMETERS -- RUNOFF PRODUCTION





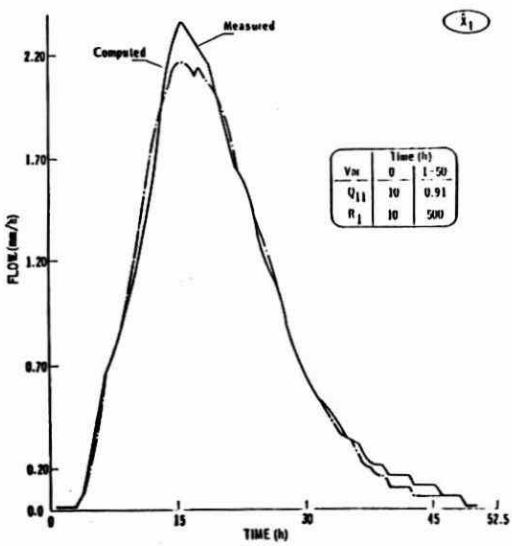
(Grand/West Montrose,16/5/74)

FIGURE 8.3: COMPARISON: RUNOFF PRODUCTION WITH TIME-INVARIANT AND TIME - VARYING PARAMETERS



(Conestogo/Drayton,16/6/71)

FIGURE 9.1: RUNOFF PRODUCTION USING KALMAN FILTER



(Nith/Nithburg,23/8/75)

FIGURE 9.2: PROPAGATION OF KALMAN GAIN IN RUNOFF PRODUCTION

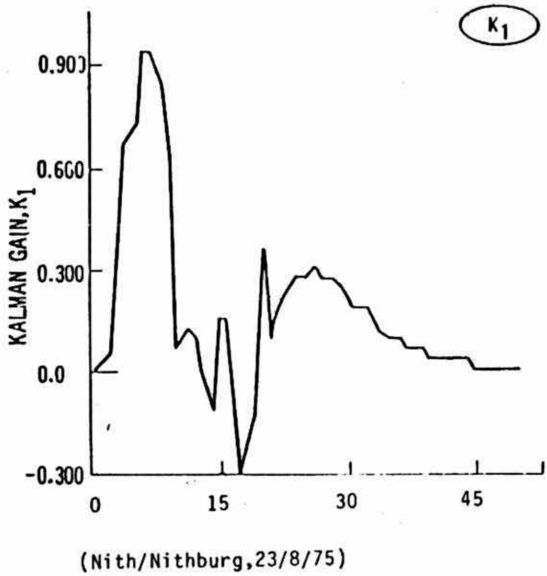


FIGURE 9.3: PROPAGATION OF ESTIMATION-ERROR-COVARIANCE IN RUNOFF PRODUCTION

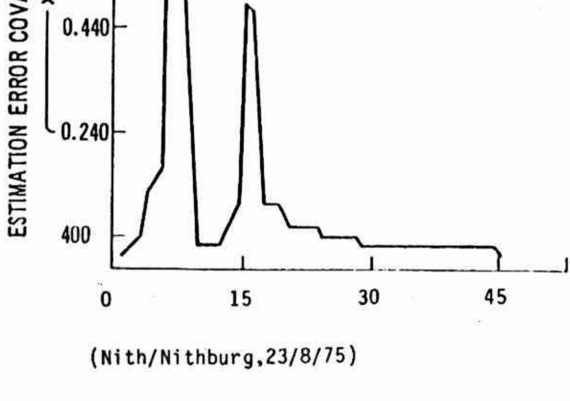
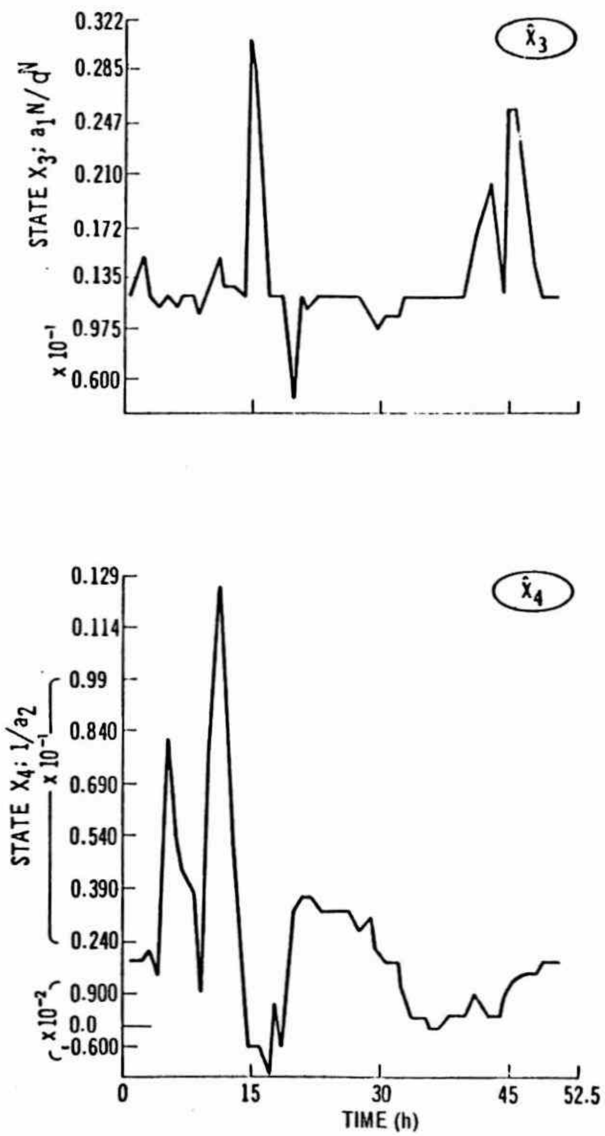
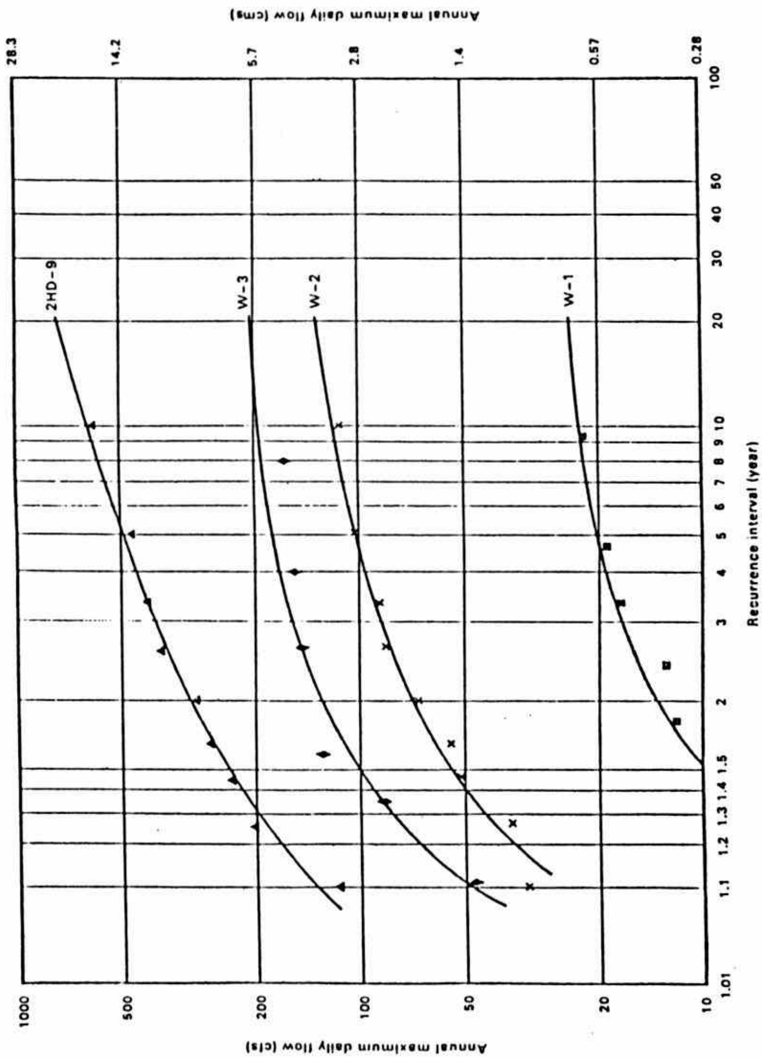


FIGURE 9.4: PROPAGATION OF STATE VARIABLES $X_3(T)$ AND $X_4(T)$: RUNOFF PRODUCTION



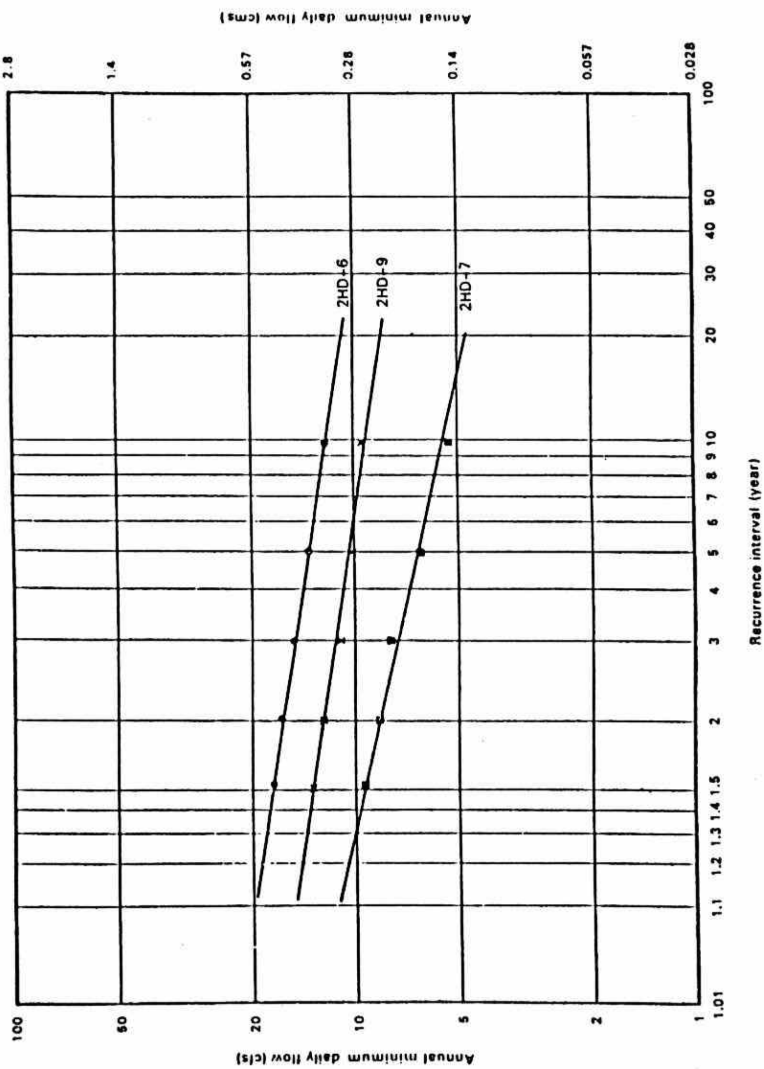
(Nith/Nithburg,23/8/75)

FIGURE 10.1: FREQUENCY CURVES FOR ANNUAL MAXIMUM DAILY RUNOFF



Frequency Curves for Annual Maximum Daily Flows: Wilmot Creek Basin (2HD-9) and Subbasins (W-1, W-2 and W-3).

FIGURE 10.2: FREQUENCY CURVES FOR ANNUAL MINIMUM DAILY RUNOFF



Frequency Curves for Annual Minimum Daily Flows: Bowmanville 2HD-6) Soper (2HD-7) and Wilmot (2HD-9) Creeks.

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Sediment Transport in Ontario Streams

How Much? When? How Often? From Where?

Trevor Dickinson[1]

Introduction

Fluvial sediment and associated nutrients and chemicals are now acknowledged to be a major cause of contamination in river and lake systems throughout North America (Duttweiler and Nicholson, 1983; International Joint Commission, 1980). More broadly, the control of soil erosion and associated stream sedimentation has been labelled a top priority in many countries (Hudson,1981). The questions arise: To what extent is the transport of sediment a problem in Ontario? In fact, how much do we know about sediment transport in Ontario streams? The purpose of this paper is to go some way in answering these questions by addressing more specifically: What are issues currently associated with sediment transported in the Ontario stream system? How much sediment is being transported? When? How frequently? Where is the sediment coming from? To what extent can we ascertain the sources? Can we begin to articulate sediment control strategies/guidelines?

Sediment Issues

One method of identifying problems associated with stream sediments has involved asking users of sediment data to delineate sediment-related issues which are currently being addressed or are likely to require attention in the near future (Conversation Management Systems, 1986). Issues identified by users are summarized in Table 1 and 2.

Most of the issues identified above have been precipitated by downstream problems brought about by the quantity and/or quality of suspended sediment arising from and transported through the contributing watershed. Persons are requesting data to quantify the volumes of sediment available for deposition in (i) stream channels - to determine the possible need for dredging and the possible impact on the habitats and populations of fish and stream biota, (ii) ponds and reservoirs - to determine the rate of decline of available flood storage and the life expectancy of the site, (iii) harbours - to determine the need for, location, and cost of dredging, and (iv) the Great Lakes - to determine temporal and spatial loading patterns. Concentration of suspended sediment, and their variability in time, are also quantities being determined by engineers designing and operating water supply intakes and by persons concerned about the improvement of stream ecology.

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Table 1

CURRENT AND FUTURE SEDIMENT-RELATED ISSUES IDENTIFIED BY USERS OF SEDIMENT DATA IN ONTARIO

Current and Future Issues	Number of Respondents
Sediment Quantity Issues	
Depositions in lakes, reservoirs, harbours	15
Deposition and/or scour in rivers (as it relates to dredging, flood potential, and power projects)	7
Deposition and/or concentration in aquatic environments	11
Concentrations at water intakes	2
	35
Sediment Quality Issues	
Source and/or sink of nutrients	22
Carrier of toxics	10
Carrier of bacteria	7
	39
Sediment Processes	
Sediment sources (e.g. land, streambanks, urban areas, forests)	25
Transport processes	2
	27
Teaching and Academic Research	
Global picture of sediment yield	2
Sediment models	2
	4

Table 2

CURRENT USES OF AVAILABLE SEDIMENT DATA

Current Uses	*Number of Users*	
Reservoir. lake, or pond sedimentation analysis	20	(15)*
Harbour or canal sedimentation analysis	14	(10)
Natural or artificial channel sedimentation analysis	11	(5)
Water quality studies	29	(20)
Aquatic habitat studies	9	(6)
Recreation planning studies	4	(3)
Academic, scientific research, and other	28	(16)

(e.g. Phosphorus loadings to the Great Lakes; sources of soil erosion and trace metals; channel erosion; coastal evolution research; environmental impact studies; dredging projects; history of airborne pollution, hydraulic and mathematical modelling, to compile information sheets on soil erosion)

*Users who also collect sediment data.

In addition to these quantitative issues, the quality of the sediments transported through and/or deposited in stream channels, ponds and reservoirs, harbours, and the Great Lakes is of increasing concern to both managers and scientists. The role of suspended sediment as a transport medium for contaminants is very clearly a major issue. There is concern about the nature and magnitude of contaminant loads associated with suspended loads; and there remain questions regarding the relation of sediment characteristics to contaminants transport, including the role of sediment as a source and/or sink for contaminants.

All of these downstream problems require resolution of many of the upstream watershed issues and/or accurate information regarding the downstream conditions relating to sediment and associated variables of interest.

Annual Suspended Sediment Loads

The order of magnitude of the volume of sediment transported in Ontario stream systems can be determined from a consideration of annual suspended sediment loads, as the bedload component of the total load has been estimated to be relatively insignificant. The mean annual suspended sediment loads per unit area are presented in Table 3 for a number of selected rivers in Southern Ontario (i.e. sediment stations established and monitored by the Water Resources Branch of the Inland Waters Directorate). These sediment yields are in the order of 75 t $km^{-2}\ yr^{-1}$, ranging from 16 for the Thames River at Ingersoll to 181 for Big Otter Creek near Vienna and Calton. These numbers are consistent in order of magnitude with estimates and computed values published earlier by Fournier (1969), Strackhov (1967), Holeman (1968), Stichling (1973), and Dickinson *et al.*, (1975). Suspended sediment loadings in the province are revealed to be only a fraction of those experienced in the mountainous and alluvial regions of Canada, and to be orders of magnitude smaller than loading observed in many major rivers of the world.

The relatively small volume of material moving through Ontario streams has been confirmed by local reservoir studies and a sediment budget developed for the Great Lakes, including consideration of northern rivers. Bottom surveys of such reservoirs as those behind the Shand and Conestogo Dams on the Grand River have revealed insignificant deposition of sediment; and the Pollution From Land Use Activities Reference Group (PLUARG, 1978), while acknowledging that stream sediments entering the Great Lakes can affect nearshore areas through localized siltation of fish habitat, drainage channels, harbours and bays, concluded that the quantity of sediment transported to the lakes does not constitute a problem in terms of volume of material.

Despite the fact that Ontario suspended sediment loads relatively small, sediment loads of sufficient volume to create depositional problems in localized areas at specific times can occur, and even low to moderate sediment loads can provide a transport medium for significant pollutant loads.

It is also evident from Table 3 that the annual suspended sediment loads on many of the selected rivers vary considerably from year to year, the maximum annual load being 3 to 8 times the minimum annual load (even for the relatively small sample sizes involved, from 9 to 17 years). Although these annual loading values are somewhat positively skewed, revealed by the means being greater than the median values (with the exception of Big Otter Creek), the skewness of annual suspended sediment loads appears to be relatively insignificant. Therefore, although single year

TABLE 3

MEAN, MEDIAN AND RANGE STATISTICS REGARDING ANNUAL SUSPENDED SEDIMENT LOAD VALUES FOR SELECTED RIVERS IN SOUTHERN ONTARIO

Sediment Station Name	WRB Station Number	Watershed Area (km^2)	Years of Record	Mean Annual Suspended Sediment Load (t km^{-2} yr^{-1})	Mean Annual Suspended Sediment Load (t km^{-2} yr^{-1})	Range of Annual Loads (t km^{-2} yr^{-1})
Ausable River near Springbank	02FF002	334	1970-83	63.9	61.0	31.1 to 108
Big Creek near Walsingham	02GC007	228	1966-83	40.2	40.2	19.9 to 57.3
Big Otter Creek near Vienna/Calton*	02GC004/ 02GC026	269	196-83	181	184	58.8 to 308
Canagagigue Creek near Floradale	02GA036	6.9	1974-1983	70.1	62.8	25.9 to 122
Credit River at Erindale	02HB002	320	1973-83	60.6	50.7	24.1 to 160
Humber River at Elder Mills	02HC025	117	1966-83	81.8	79.9	28.8 to 123
South Nation River near Plantagenet Springs	02LB005	1470	1972-83	170	226	50.4 to 398
Thames River at Ingersoll	02GD016	200	1963-83	16.3	13.7	7.74 to 28.7

*Combined record of Big Otter Creek stations at Vienna and Calton.

determinations of suspended sediment loads do not provide precise estimates of the long term mean and should not be considered as such, both mean and median values of 10 or more years of data provide good indices of the central tendency of annual suspended sediment loads in the province.

Seasonal Variability

Individual suspended sediment load hydrographs, such as those shown in Figures 1 and 2, provide a basis for examining seasonal trends; and a composite

FIGURE 1: SAMPLE SUSPENDED SEDIMENT LOAD HYDROGRAPH FOR THE THAMES RIVER AT INGERSOLL

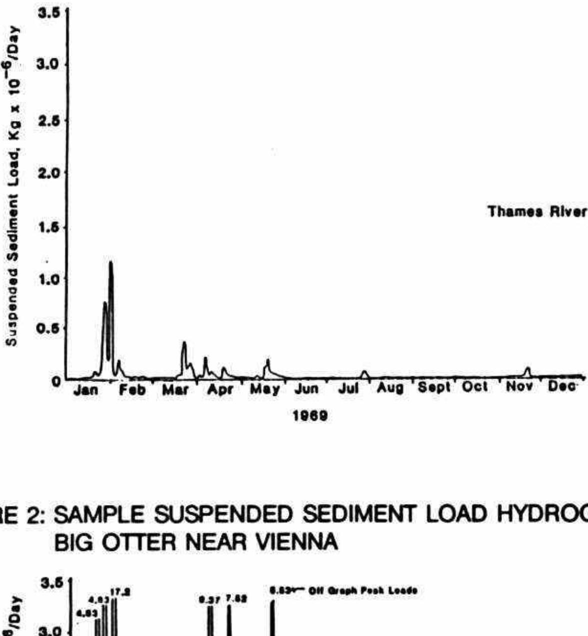


FIGURE 2: SAMPLE SUSPENDED SEDIMENT LOAD HYDROGRAPH FOR BIG OTTER NEAR VIENNA

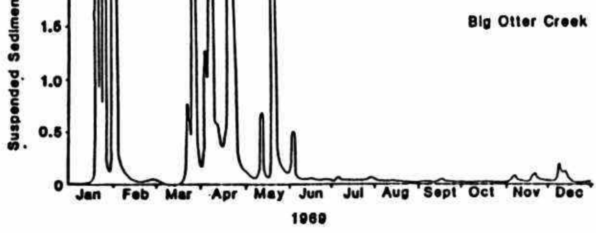
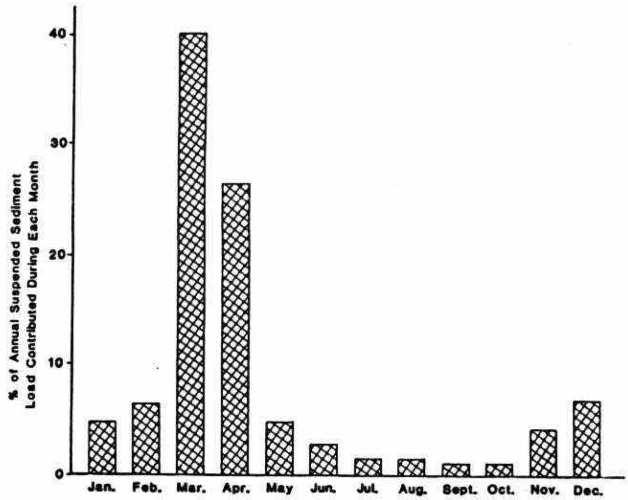


FIGURE 3: ANNUAL DISTRIBUTION OF SUSPENDED SEDIMENT LOADS FOR RIVERS IN SOUTHERN ONTARIO



of the annual hydrographs available for the selected rivers noted in Table 3 provides the summary seasonal pattern shown in Figure 3. (The monthly percentages are means of the median monthly percentage values determined for each month for each selected river, the median values being most indicative of the central tendency of the highly skewed monthly data). The seasonal pattern for individual rivers varies somewhat but not significantly from that shown in Figure 3.

It is evident from the sample suspended sediment load hydrographs in Figure 1 and 2, and from the composite suspended load hydrograph in Figure 3, that daily sediment loads in Ontario streams vary dramatically over a wide range of values. However, they tend to follow a very distinctive seasonal pattern: the bulk of the annual suspended load is transported during the spring period, 65 percent moving downstream during March and April. This pattern closely parallels the seasonal distribution of flood occurrences in Southern Ontario, 60 percent of the annual extremes occurring during the same two months (Dickinson, 1972). Seasonal percentages for the individual selected rivers are summarized in Table 4, further exemplifying the strong seasonal pattern, and revealing some of the variability to be expected among the river basins.

Seasonal patterns in suspended sediment loads in Northern Ontario rivers have not received the attention of those in the south. However, from the Water Resources Branch stations and the data base assembled during the PLUARG studies, it is generally known that the northern rivers exhibit a seasonal pattern similar to that noted above, but with a peak occurring somewhat later, corresponding to the northern peak runoff period.

TABLE 4

SEASONAL DISTRIBUTION OF SUSPENDED SEDIMENT LOADS FOR SELECTED RIVERS IN SOUTHERN ONTARIO (Data Source: Published records of the Water Resources Branch, Inland Waters Directorate)

Sediment Station*	Seasonal Load as a % of the Annual Load		
	Spring**	Summer**	Fall/Winter**
Ausable	74.2	7.1	18.7
Big	68.2	13.9	17.9
Big Otter	76.0	6.9	17.1
Canagagigue	83.7	1.2	15.1
Credit	84.3	6.5	9.2
Humber	85.4	6.0	8.6
South Nation	83.7	2.4	13.9
Thames	63.5	6.7	29.8
Mean Values	77.4	6.3	16.3

*Station names abbreviated after Table 3.

**Spring = February through May; Summer = June through September; Fall/Winter = October through January.

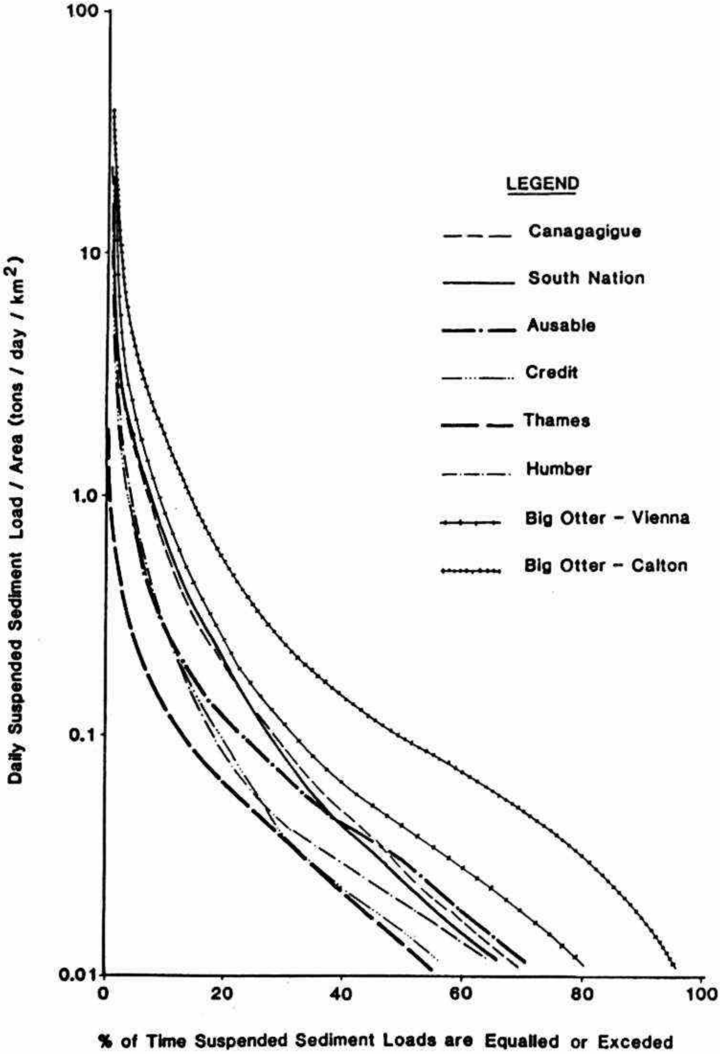
Event Orientation

The variability in seasonal and daily suspended sediment loads noted above can be further explored in terms of the sediment duration curves presented in Figures 4 and 5. Figure 4 is a conventual plotting of the percentage of time which daily suspended sediment loads (expressed per unit area) can be expected to be equalled or exceeded over the long term. Figure 5 offers another representation of the same data, plotting the percentage of the total suspended load (carried by each river) contributed by suspended loads greater than or equal to selected values versus the percentage time that these selected values might be expected to be equalled or exceeded.

From Figures 4 and 5 it is abundantly clear that daily suspended sediment loads in Ontario streams exhibit highly skewed frequency distributions of somewhat different shapes. The mean daily loads (i.e. the values presented in Table 3 divided by 365) can be seen to be equalled or exceeded less than 20 percent of the time. As a result, mean daily suspended sediment loads do not provide good indications of the central tendency of the daily data.

A logical consequence of the occurrence of daily loads which exhibit highly skewed distributions is, as revealed in Figures 4 and 5, that a large percentage of the annual load is transported downstream in a very small percentage of the time. For example, a majority of the annual load (i.e. 65 percent) - and, in most cases, the vast majority of the annual load (i.e. 80 to 90 percent) - is expected to be

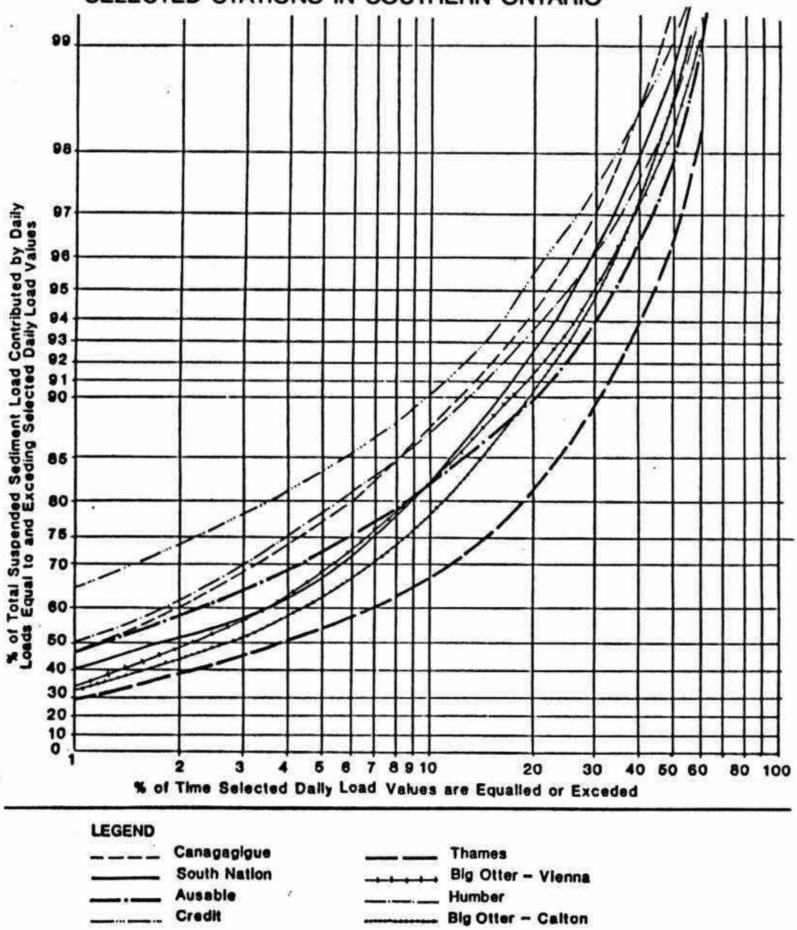
FIGURE 4: DAILY SUSPENDED SEDIMENT LOAD DURATION CURVES FOR SELECTED STATIONS IN SOUTHERN ONTARIO



delivered in less than 10 percent of the time (i.e. less than 36.5 days each year). For all selected rivers except the Thames River at Ingersoll, more than 60 percent of the annual load is transported in less than 16 days each year; for the Thames, more than 50 percent is transported in 16 days.

The duration curves of Figures 4 and 5, therefore, reveal not only that the daily suspended sediment loads are extremely variable and highly skewed, but also that the movement of suspended sediment in Ontario streams may be considered to be

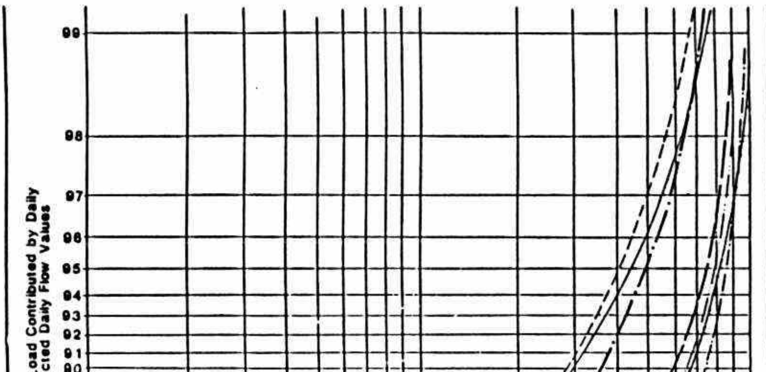
FIGURE 5: DIMENSIONLESS SEDIMENT LOAD DURATION CURVES FOR SELECTED STATIONS IN SOUTHERN ONTARIO



an event-oriented process. When these results are compared with similar statistics for streamflow itself, the extent to which suspended loads are event-oriented and linked to extreme events is revealed. Figure 6, a diagram comparable to Figure 5 but developed from streamflow data, reveals that daily streamflow equalled or exceeded 10 percent of the time accounts for only 40 to 70 percent of the total flow; and flows equalled or exceeded 10 percent of the time accounts for only 40 to 70 percent of the total flow; and flows equalled or exceeded 5 percent of the time account for but 25 to 55 percent of the flow. So although suspended sediment flows may be strongly linked to or determined by streamflow, it is clear from Figure 5 and 6 that the daily suspended sediment load variable is more extreme-event oriented that the equivalent flow variable.

From the above results, it is clear that reliable estimates of suspended sediment loads in Ontario streams are contingent upon the application of a sampling scheme

FIGURE 6: DIMENSIONLESS STREAMFLOW DURATION CURVES FOR SELECTED STATIONS IN SOUTHERN ONTARIO

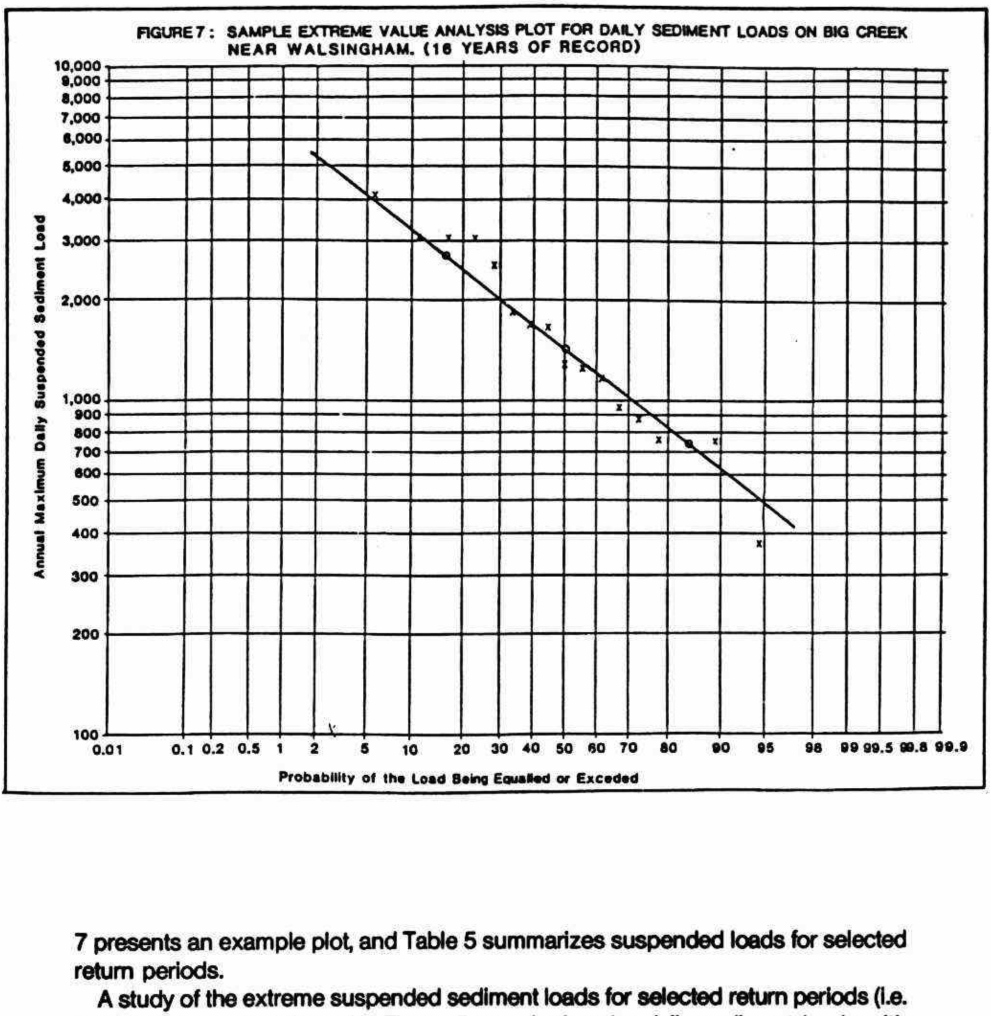


in time that ensures the obtaining of good sediment samples during the brief periods when most of the suspended load is delivered. Sediment sampling programs in the province should key on significant runoff events during the season when these events may be expected to occur.

Extreme Values

The duration curve analysis, indicating that the bulk of suspended sediment is transported during major events, begs the questions: How much of the load can be expected to be transported by events with longer return periods? Is there any point measuring loads during much of the rest of the time? To explore answers to these questions, extreme value analyses were performed on the annual series of maximum daily suspended sediment loads determined for the selected river stations. A simple log-normal probability distribution was assumed to apply to each case. Figure

FIGURE 7: SAMPLE EXTREME VALUE ANALYSIS PLOT FOR DAILY SEDIMENT LOADS ON BIG CREEK NEAR WALSINGHAM (16 YEARS OF RECORD)



7 presents an example plot, and Table 5 summarizes suspended loads for selected return periods.

A study of the extreme suspended sediment loads for selected return periods (i.e. Figure 7) in conjunction with Figure 5 reveals that the daily sediment loads with return periods of two years or greater (i.e. loads which can be expected to be equalled or exceeded 0.5 percent of the time) account for approximately 40 percent of the total sediment load. Annual peak events contribute a similar, or slightly larger, significant portion of the total load. In comparison, on the basis of Figure 6, daily streamflows with return periods of two years or greater account for about 8 to 20

percent of the total flow. These results confirm the similar but less specific observations of Archer (1960), Wolman and Miller (1960), and Piest (1965).

These results regarding extreme values confirm that the reliable estimation of sediment loads requires careful sampling of significant events, including sediment load occurrences with return periods of two years of greater and annual peak events.

TABLE 5

EXTREME DAILY SUSPENDED SEDIMENT LOADS IN SELECTED ONTARIO STREAMS

Data Source: Published records of the Water Resources Branch, Inland Waters Directorate)

	Daily Suspended Sediment Loads ($t\ km^{-2}\ day^{-1}$) for Return Periods of			
Sediment Station*	2 years	5 years	10 years	25 Years
Ausable	8.44	15.3	20.6	28.8
Big	6.21	10.7	14.2	19.1
Big Otter	47.6	74.4	92.9	119
Canagagigue	62.6	104	135	181
Credit	37.6	103	172	303
Humber	35.0	55.1	68.4	88.0
South Nation	16.8	38.8	59.2	93.2
Thames	4.30	8.35	11.8	17.2

*Station name abbreviated after Table 3.

Nature of Stream Sediment Loads

The physical and chemical properties of fluvial sediments transported from agricultural watersheds are quite different from the soil materials from which they were derived (Wall *et al.*, 1982). This observation reflects the selective nature of the soil erosion process towards the finest, most erodible, soil particles. The texture of the fluvial suspended sediment in all agricultural regions in Ontario is usually a heavy clay (60%) with clay contents ranging from 59 to 98%. This represents an enrichment of clay from one to four times that found in watershed soil material. Organic matter levels of suspended sediments are analogous to surficial soil material (%), while the cation exchange capacity of the suspended sediments is two to three times greater than soil materials.

Sediments that settle out on stream beds during transport are often resuspended and transported at a later date under a high stream energy regime. The texture of

these bottom sediments in Ontario agricultural watersheds is usually a sandy loam with clay contents ranging from 10% to 35% and sand content from 25% to 90%. Enrichment of sand in bottom sediments over soil materials of from 1 to 4 times reflects the selectivity of the transport process to the fine soil particles. The organic matter content of the bottom sediments is usually <3%, while cation exchange capacities range from 10 to 25 meg/100g. The clay mineralogy of the watershed soils, fluvial suspended sediments and bottom sediments are analogous, with mica, quartz and vermiculite predominant.

Spatial Variability and Sources of Suspended Sediment

The suspended sediment loads presented earlier for the selected river stations in the province (i.e. Table 5) exemplify the range of variability which can be expected spatially, at least in the southern portion of the province. The question arises: Can variation in sediment loads in Ontario be explained by variations in geomorphic physiographic, climatic, and/or land use characteristic?

The sediment yield of a basin has been noted in the literature to be a function of a number of factors, including climate, basin geomorphology, soil type and land use. Schumm (1954) and Maner (1958) have noted apparent relationships between basin sediment yield and relief ratio. Williams and Knisel (1971) have found that sediment yield can be related to drainage density. However, there appears to be no simple relationship between average annual suspended sediment load and either relief ratio or drainage density in the province (Dickinson *et al.*, 1975; Ongley, 1976).

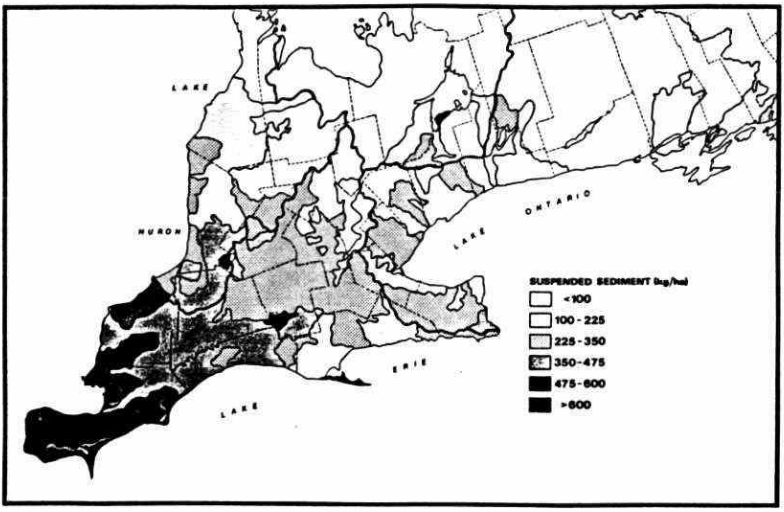
For information in the province regarding the possible relationship of watershed sediment yield to more specific soil and land use variables, one must turn to a suspended sediment data set assembled in conjunction with the PLUARG studies. This data set was developed from the sampling of suspended sediments discharged from 11 small (<6,000 ha) agricultural watersheds in Southern Ontario (Wall *et al.*, 1982). The unit area suspended sediment yields ranged from <100 to 1000 kg ha^{-1} yr^{-1} in a two year study during 1975 and 1976, corresponding to the orders of magnitude identified earlier in this section and by Dickinson *et al.* (1975).

Wall *et al.* (1982) found that the annual suspended yield form the 11 small agricultural watersheds in Southern Ontario could be related to land use and physiographic parameters, specifically the percentage row crop in the watershed and the percentage clay in the surface soil, according to the expression:

$$y = -204 + 7.9\ (\%\ \text{Row Crop}) + 11.0\ (\%\ \text{Clay})$$

where y = predicted sediment yield, kg ha^{-1} yr^{-1}. This relationship explained 64 percent of the total variation in the sediment yield data (i.e. $R^2 = 0.64$). This relationship was used as a basis for estimating the mean suspended sediment yield to the Great Lakes for Canadian agricultural land to be 201 kg ha^{-1} yr^{-1} (Wall *et al.* 1982), and for the mapping shown in Figure 8. When compared to the mean suspended sediment load determined earlier in this section (on the basis of I.W.D.-W.R.B. data), this value is somewhat low but plausible, considering that it is meant to apply to a very large area. Wall *et al.* (1982) went further, on the basis of this figure, to estimate the total agricultural suspended yield to the Lower Great Lakes for the Canadian side to be approximately 650 x 10^3 t/yr.

FIGURE 8: SPATIAL DISTRIBUTION OF AGRICULTURALLY DERIVED FLUVIAL SEDIMENT LOAD IN PART OF THE CANADIAN GREAT LAKES BASIN



Variations in the PLUARG watershed sediment yields were further attributable to differences in the quantity of sheet and rill erosion, in the sediment transport systems, and in the amounts of streambank erosion. To explore the relative significance of some of these sources, sediment yields were partitioned into streambank and cropland yield components, affording results such as those shown in Table 6 (Wall *et al.*, 1982).

The tabulated values reveal considerable variability from basin to basin with regard to both the absolute and relative quantities of sediment yielded by the watersheds. It is clear that the bulk of suspended sediment in rural Southern Ontario streams emanates from cropland, with sediment delivered from sheet and rill erosion contributing 70 to 100 percent of the annual load. Bank erosion was estimated to contribute between 0 and 30 percent of the annual sediment load. Watersheds with highly erodible soils, erosion-sensitive land use, and an efficient sediment transport system (e.g. watershed AG-1 and AG-5) generated relatively high sediment yields. The lowest yielding basins (e.g. AG-6 and AG-11) were those with soils that were not prone to erode, land use that protected the soil against erosion forces, and features to minimize sediment transport. Factors such as stream buffering by grass or trees and stream channel density appeared to have considerable effect on the determination of sediment yields, causing areas with highly erodible soils and erosion-sensitive land uses (e.g. AG-3 and AG-7) to yield surprisingly low sediment loads.

The PLUARG studies, like the earlier-noted results in this section, also revealed that about 75 percent of the annual suspended sediment yield is transported in February, March and April. Streambank erosion is also maximum during this period (Knap and Mildner, 1978).

TABLE 6

MEASURED AND PARTITIONED SUSPENDED SEDIMENT YIELDS (Data Source: IJC-PLUARG Canadian Agricultural Watershed Studies)

Watershed	Mean Stream Sediment Yields[1] 1975-1977	1976	1976 Streambank Erosion Estimates[2]	1976 Cropland Sediment Yield Estimates[3]	Streambank Yield as Proportion of Total Sediment Yield	Cropland Yield as Proportion of Total Sediment Yield
	kg ha^{-1} year^{-1}				%	
AG-1	961	998	223	775	22	78
AG-2	153	140	10	130	7	93
AG-3	197	258	24	234	9	91
AG-4	464	419	137	282	33	67
AG-5	274	351	5	346	2	98
AG-6	60	64*	10	54	16	84
AG-7	98	43	7	36	16	84
AG-10	300	375	17	358	5	95
AG-11	—	19*	65	—	—	—
AG-13	499	310	41	269	13	87
AG-14	139	135	75	60	—	—

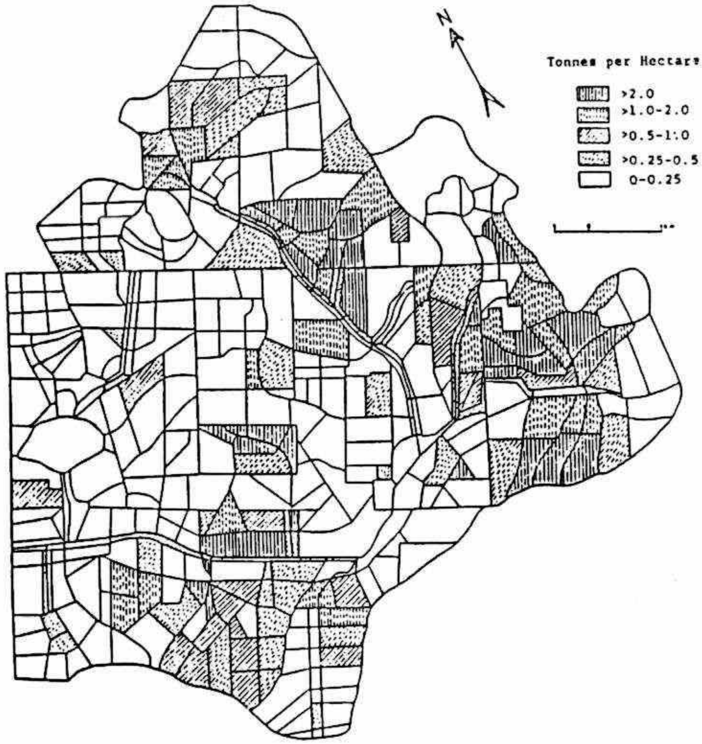
[1] Using NAQUADAT method of sediment yield computation (Demayo and Hunt, 1975).
[2] Knap *et al.* (1979).
[3] 1976 Stream sediment yields minus 1976 streambank erosion estimates.
* Problems with streamflow measurement account for the very low sediment yield.

Field Sources

A Post-PLUARG study by Dickinson and Pall (1982) explored the question of spatial variability of suspended yields further on the basis of a data set developed in conjunction with Thames River Implementation Committee (TRIC). Sediment data were assembled for five small agricultural watersheds in the Thames River Watershed during 1980 and 1981, and an erosion and sediment modelling exercise involving GAMES (Guelph model for evaluating the effects of Agricultural Management systems on Erosion and Sedimentation) was used to explore spatial variations in sediment yield and to identify sources of significant suspended sediment. Coleman (1982) employed a similar but more qualitative model on a larger basin in the same area.

The results of this Post-PLUARG study have generated many insights into the generation of suspended sediment loads in rural parts of Southern Ontario. Although the average sediment yield per unit of watershed area for the Thames River agricultural watershed was not large (i.e. 0.8 t ha^{-1} yr^{-1}), the suspended sediment amounts estimated to be yielded by field-sized areas within the small watersheds were extremely variable (i.e. 0 to 14 t/ha for the spring months), particulary in the rolling upland watersheds. It followed from these results, that a great majority of the suspended sediment leaving the upland watersheds emanated from a very small percentage of the area. For example, 62 percent of the spring sediment load in the

FIGURE 9: SPATIAL VARIATION OF SPRING SEDIMENT YIELD ON STRATFORD/AVON BASIN 1, AS GENERATED BY GAMES



Stratford-Avon Basin 1 was generated in 15 percent of the area (14 percent of the load was generated in 1 percent of the area). Figure 9 reveals this spatial distribution of sediment yield. Fifty-five percent of the spring load in Basin 2 was generated in 9 percent of the watershed area (35 percent of the spring load was generated in 4 percent of the area); and 71 percent of the spring load in Basin 3 was generated in 19 percent of the watershed (23 percent of the load was generated in 2 percent of the area). Sediment yield from lowland areas was found to be much more uniform.

The models and applications of Dickinson and Pall (1982) and Coleman (1982) are the most definitive to date to link suspended sediment yields in Ontario to watershed physiographic and land use factors. These models and others are presently undergoing extensive verification in a number of locations in the province. However, only after further testing in a yet wider variety of conditions, will existing sediment yield models or modifications of them be broadly applicable for estimating sediment loads and sources.

Impact of Erosion and Sediment Control Practices

The previous results have already yielded implications regarding the control of soil erosion and transport. For example, it is evident that selective control of highly erodible sites in landscape similar to the Stratford/Avon Watersheds could greatly reduce both the total watershed erosion and the total sediment loads. On the other hand, any reduction desired in the overall watershed erosion amounts or sediment yields in lowland areas would require that control measures be applied widely over the areas.

To explore the potential impact of specific changes in soil and crop management practices, GAMES was applied to a variety of sets of input data developed in accordance with selected alternative agricultural management scenarios for a number of selected watersheds (Dickinson and Pall, 1982). The scenarios selected are included in Table 7, with the corresponding estimates of potential soil loss and sediment delivered for one of the watersheds. Potential reduction in soil loss and watershed sediment load have been determined to '80-'81 reference levels for no residue and fall ploughing.

TABLE 7

SUMMARY OF GAMES OUTPUT FOR SELECTED MANAGEMENT PRACTICES-STRATFORD/AVON UPPER WATERSHED

Management Practice	Residue Management	Gross Erosion (tonnes)	Sediment Delivered to Outlet (tonnes)	%Reduction in Gross Erosion	%Reduction in Sediment Delivered
Fall moldboard ploughed	crop residues removed before ploughing				
	-100% of area	2582	167	Reference levels	
	crop residues left on field before ploughing				
	-100% of area	1830	44.0	29.1	73.7
	-45% of area	1872	52.0	27.5	68.9
Spring moldboard ploughed	crop residues removed from field				
	-100% of area	2154	137.7	16.6	17.5
	-45% of area	2182	138.6	15.5	17.0
	crop residues left on fields over winter				
	-100% of area	1278	30.6	50.5	81.7
	-45% of area	1355	37.7	47.5	77.4
Conservation tillage	minimum of crop residues left on fields				
	-100% of area	1275	90.6	50.6	45.7
	45% of area	1348	92.9	47.8	44.4
	maximum of crop residues left on fields				
	-100% of area	703	17.3	72.8	89.6
	45% of area	813	23.9	68.5	85.7

A number of observations are prompted by the model output for the alternative management scenarios and a few as presented below for discussion.

(i) Estimated percentage reduction in suspended sediment delivered to the stream are for some changes in management practice very similar to the reduction estimated for the potential soil loss. For other changes in management practice, the estimated reductions in suspended sediment and soil loss are quite different. This non-linear response results from potential soil loss being altered by changes in land use and cropping and sediment load being affected by changes in not only land use and cropping but also surface roughness.

(ii) Relatively minor reductions in watershed soil loss (i.e. up to approximately 25 percent) are estimated to be achieved by the introduction of cross-slope farming in the more rolling upland areas (e.g. Stratford/Avon Watersheds), site-specific control measures as strip-cropping and grassed waterways in the upland areas, or conservation tillage and forage crops in limited areas of flatter lowland areas.

Minor reductions in sediment delivered to the stream are estimated to be achieved by those changes in management practice yielding similar reductions in potential soil loss. It may be noted that site-specific remedial measures such as strip-cropping on rolling land and buffer strips of forage on more level areas are estimated to yield significantly greater reductions in sediment load than in soil loss.

(iii) For moderate to large reductions in watershed soil loss (i.e. up to 50 and 75 percent), the extensive use of crop rotations, surface residue management and conservation tillage would appear to be required on all watersheds.

For moderate to large reductions in watershed sediment load, widespread use of crop rotations, residue management, and conservation tillage would be required in lowland watersheds. In upland areas, these same management practices or strategically selected site-specific measures are estimated to effect sizeable reductions in sediment loads.

Concluding Comments on Erosion and Sediment Control

Broad physiographic features of the Southern Ontario landscape provide a basis for selection of effective and most economical soil erosion and sediment control measures e.g. the average soil loss and sediment yield rates in rolling upland watersheds are not likely to be excessive but there are likely to be localized soil erosion problems. Identification of site-specific problem areas and implementation of appropriate remedial measures (e.g. cross-slope farming, strip-cropping, and grassed waterways for minor reduction is soil loss; crop rotations, surface residue management, and conservation tillage for larger reductions) will go a long way to improving the soil erosion picture in such landscapes. Further, sediment sources in upland watersheds are even more localized than erosion problems. Therefore, if stream

sediment loads are deemed to be problematic, control of a limited number of selected sediment sources will provide particularly economic solutions.

In lowland watersheds of Southern Ontario, sheet and rill erosion is likely to present neither general nor local problems. However, stream sediment loads may well be judged to be excessive. If soil losses and/or stream sediment rates were deemed to present problems in lowland areas, remedial measures would require extensive changes in overall soil and crop management systems. It is evident that the options available for reducing soil erosion and stream sediment loads in lowland watersheds are more limited and more expensive to implement than options available for rolling upland watersheds.

Acknowledgements

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Impact of Sediment on River Ecosystems

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Erosion and sedimentation are natural processes. However, man's activities, especially agriculture, have greatly increased soil erosion and the input of sediments to streams in southern Ontario. (stream refers to any running water ecosystem from small headwater streams to large rivers). Sediment loads are 10 to 100 times greater to streams in agricultural and urbanized areas than areas in forest of idle land (PLUARG, 1978). About 80% of this loading is estimated to come from sheet and rill erosion from cultivated fields. In other studies, large sediment inputs have been recorded from roadsides, e.g., from drainage ditches leading into streams (Burns, 1974; Likens, 1984). Increased sediment loads can affect the ecological status of a stream. Turbidity and sedimentation processes are particularly important in influencing the stream fish and invertebrate community structures. The effects of these processes on the stream biota have been known for some time, e.g., Ellis (1937) related a decrease in the number of sites with a good mixed fish population with increased turbidity. Currently, environmental researchers are paying more attention to sediments because of their importance in the transport of nutrients and toxic chemicals. There is also increased public awareness of soil erosion and sedimentation problems in Ontario. This is largely as a result of the conversion of farmland to residential and industrial uses, and a reduction in the quality of farmland due to poor soil conservation practices resulting in erosion. To a lesser extent, the loss of fishing opportunities, cost of dredging sediment deposited in harbours, and problems with local flooding have also influenced public perception. For example, in Toronto, sediment deposition at the mouth of the Don River has caused local flooding following storm events.

Although the present discussion deals only with the impact of sediments on streams, it is often impossible to distinguish between the effects caused by sedimentation, altered flow regimes and higher water temperatures (Whiteley, Logan, Imhof et al., this volume). These parameters are interlinked and are the result of deforestation of stream banks for agriculture and urbanization. The approach taken here will be to first briefly discuss the physical/chemical aspects of sediment transport in streams, followed by retention devices, and then the biological impact of sediments on stream communities.

Physical/Chemical Aspects of Sediment Transport

Sediment is classified on particle size (Table 1). The size of the particle and current velocity determine how the particle is transported. Coarser particles move primarily by rolling along the stream bottom as part of the bedload. Hence, their concentrations are low in the water column. In comparison, silt and clay are transported in suspension, and their concentrations are generally uniformly distributed throughout the water column (Culbertson, 1977). An approximation of the size of particles moved by various water velocities is given in Table 2. Obviously, the

average velocity that a reach of stream experiences will influence the nature of its substrate. In general, a silt and mud bottom may be expected where average water velocities are less than 20 cm/sec. At mean velocities between 20 and 40 cm/sec, the substrate may be predominantly sand, whereas stones and gravel may be primarily found at higher mean velocities (Hynes, 1971).

TABLE 1: Sediment Size and Mode of Transport in Streams (After Culbertson, 1977)

Sediment	Size Class (mm)	Transport
boulders	256	bedload
cobble	64 - 256	bedload
gravel	2 - 64	bedload
sand	0.062 - 2	bedload or suspended
silt	0.004 - 0.062	suspended
clay	0.002 - 0.004	suspended

TABLE 2: Sizes of Particles that May be Moved at Various Water Velocities (Hynes, 1971)

Velocity (cm/sec)	Diameter of particle (cm)
10	0.2
25	1.3
50	5.0
75	11.0
100	20.0
150	45.0
200	80.0
300	180.0

With an increase in water velocity, there is an increase in suspended sediment concentrations and size of particles transported (Table 1) because shear stress is proportional to velocity squared (Hynes, 1971). However, with an increase in the suspended load, there is a decrease in the turbulence and resistance to flow by the streambed, so that there must be a further increase in water velocity to carry the same sediment load. The relationship is further complicated by other factors, such as compacting or cementing of substrate between runoff events, which influence the relationship between suspended sediment concentrations and discharge, and hence increase the variability in our modelling attempts to predict sediment loads.

Verhoff and Yaksich (1982) reported that maximum discharge, time period into the discharge event, and water temperature were significant variables in correlating mean suspended sediment concentrations during storm events. Mean suspended sediment concentrations were lower for storms of long duration, probably because longer storms tend to have long declining stages during which suspended solids concentrations are lower. Concentrations were also negatively correlated with the number of days between events. This was attributed to consolida-

tion of sediments between events, so that sediment was not as readily resuspended. However, frequent storms may also result in lower concentrations. Bilby and Likens (1979) reported that suspended sediment concentration and peak in suspended sediment export in an initial storm were 250% and 30% higher, respectively, than those during a second storm which occurred two days later. Concentrations were also lower during their second storm than other storms that followed at an interval of five or more days between storms. Thus, suspended sediment concentrations are influenced by a complex set of conditions, including the nature of the river ecosystem.

Unit area loads of sediment to streams vary widely, and are affected by soil type, physiography, watershed area, land use and climatic variables. In southern Ontario, suspended sediment loads from 11 small agricultural watersheds ranged from less than 100 to 1,000 kg/ha/year in a two-year study (Wall *et al.*, 1982). Bank erosion was estimated to contribute between 0 and 30% of the suspended sediment, whereas sheet and rill erosion of cropland contributed 70 to 100%. Only about 20% of the land surface area is believed to contribute 90% of the sediment load (PLUARG, 1978; Dickinson Chapter 3). This illustrates the importance of site-specific conditions in contributing sediments to streams.

Sediment inputs to streams and its transport downstream are associated with high discharge events with about 80% of the sediment export from rivers occurring in late winter-early spring, in association with snowmelt in most years (Wall *et al.*, 1982;Figure 3, Dickinson Chapter 3). Variation in loads from year to year is largely due to differences in runoff. Suspended sediment concentrations in Ontario rivers

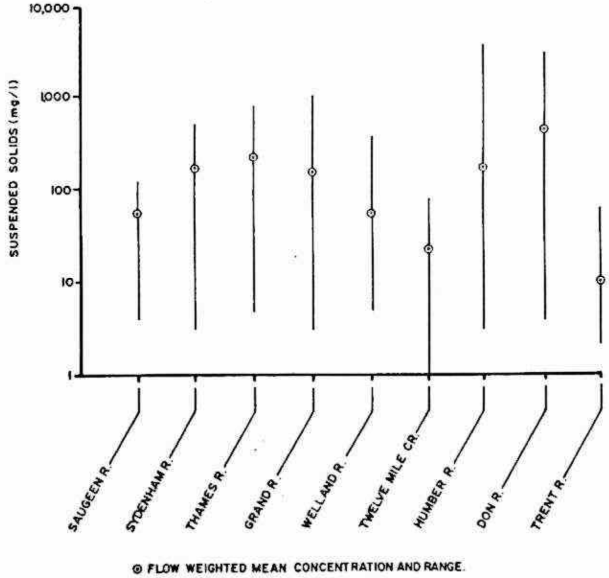

Figure 1. Concentrations of suspended solids recorded in several Ontario rivers during the 1980 water-year (modified from Eddie and Orm, 1982).

may range from nearly nil during low flows to several thousand mg/L during high discharge events (Figure 1).

Unit area sediment loads are much greater from land under intensive agriculture and urban areas, especially those areas under construction, than land in forest or pasture where livestock is not allowed access to the streams (Table 3). Examination of the suspended sediment load to the Great Lakes reveals that Lake Erie received about 6.5 million tonnes of sediment in 1976, a load far greater than that of the other Great Lakes (Table 4). The elevated suspended load for Lake Erie is associated with a greater percentage of its basin in cropland and a smaller portion in forest.

Table 3: Unit Area Sediment Loads from Different Land Use (PLUARG, 1978)

Land Use	Sediment Load (kg/ha/yr)
Residential	620 - 2,300
Commercial	50 - 830
Industrial	400 - 1,700
Under Construction	27,500
Cropland	20 - 5,100
Pasture	30 - 80
Forest	1 - 820

In association with sediment in transport are sediment-bound nutrients, particularly phosphorus, and toxic chemicals such as heavy metals, polychorinated biphenyls (PCBs) and pesticides (PLUARG, 1978; Munawar *et al.*, 1984; Allan, 1986). Again, Lake Erie receives the largest tributary input of nutrients (phosphorus) and toxic chemicals (Table 4).

Table 4: Land Use and Estimated Tributary Pollutant Loads for the Great Lakes in 1976 (PLUARG, 1978)

	Land Use		Pollutant Load (tonnes/year)				
Lake	% Forest	% Cropland	Suspended Sediment ($x10^6$)	Phosphorus ($x10^3$)	Lead	PCBs	Mercury
Superior	94	1	1.4	2.1	81	0.033	0.86
Huron	66	9	1.1	3.0	51	0.013	0.120
Erie	17	39	6.5	11.9	896	0.530	1.530
Ontario	56	11	1.6	4.9	206	0.140	0.370

The dynamics of phosphorus in rivers may serve as an example for that of other sediment-bound pollutants (Bird, 1986). The phosphorus load is primarily associated with suspended sediments, particularly the finer fractions (i.e. clay and silt). In the case of the Great Lakes, about 60 to 80% of the total phosphorus load is sedi-

ment-bound, and about 33% of the sediment-bound phosphorus in Canadian tributaries is bioavailable (PLUARG, 1978). This alludes to the importance of sediments in the transport of pollutants.

Transport of suspended sediment is by resuspension and deposition. A hysteresis effect is seen in suspended sediment concentrations during high discharge events, i.e., their concentrations peak before that of flow. The distance travelled by suspended sediment will depend on the magnitude and duration of the discharge event, size fraction of sediment and presence of retention devices. Verhoff *et al.* (1979) calculated that the mean distance that suspended sediments travelled in the Sandusky River, Ohio, during a storm event was 30 km in a headwater tributary and about 220 km in a downstream reach. This suggests that it may take several storm events to move suspended sediments from headwater areas to downstream lakes, but only a couple of high discharge events to move sediment from downstream reaches to the lake. Likewise, in a study of the phosphorus budget of a woodland stream over a 13-year period, phosphorus was retained by the stream most years, but in years of higher flows there was a net export of phosphorus (Meyer and Likens, 1979). The yearly ratio of phosphorus export to phosphorus input to streams eventually reach downstream lakes. Thus, if sediment inputs to our streams are controlled, they will quickly flush themselves clean.

Sediment Retention Devices

Retention of sediment and associated pollutants may occur in the streambed, debris jams (accumulation of logs, branches and small sticks that form obstructions in the stream channel), wetlands, flood plains, reservoirs and lakes, whereas retention of pollutants released from sediment may also occur in the biota.

Large amounts of silt may occur in backwaters and shallows, or as a temporary sheet over sand during low flow, but silt is not generally a major component of the substratum in the main channel of the majority of rivers, even at low flows (Hynes, 1971). Deposition of sediments also occurs in the quiet areas downstream of rocks and boulders and in pools, most of which is resuspended during major discharge events.

The importance of natural forested areas in increasing resistance to flow and increasing sediment deposition is illustrated in Figure 2. Since sediment transport is inversely proportional to resistance raised to a power ranging from 1.3 to 2, a two-fold increase in resistance may result in as much as a four-fold decrease in sediment transport.

Debris jams are a natural feature of woodland streams. They add roughness to the channel, slowing the flow of water so that suspended sediments settle out. Their importance in trapping sediment is illustrated by the finding that experimental removal of debris jams from a stretch of river increased the export of particulates by more than 500% (Bilby, 1981).

Debris jams have been largely removed from agricultural and downstream areas for aesthetic or navigational reasons. This is a practice that should be discouraged, since they not only slow the flow of particulates (sediment and particulate organic matter-food for stream invertebrates) downstream, but provide important habitat for fish and invertebrates (Bird and Kaushik, 1981). Numerous studies on the west coast of North America have concluded that debris jams add stability to river ecosystems, and provide critical habitat for trout and salmon during summer low flow periods and

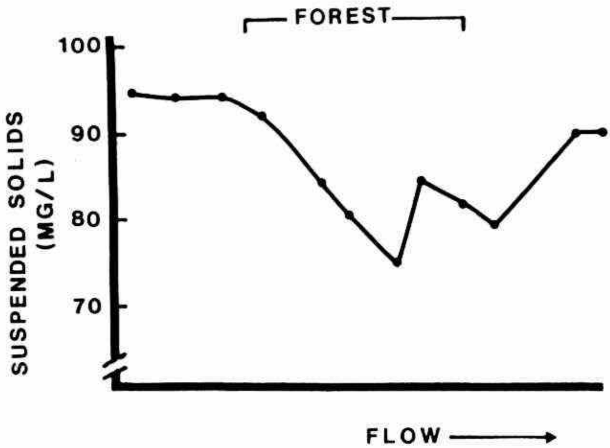

Figure 2. Concentrations of suspended solids in an agricultural headwater stream that passes through a forested area (modified from Karr and Schlosser, 1978).

during the winter months (Elliott, 1986; Johnson *et al.*, 1986; Lisle, 1986). In the Credit River, Ontario, debris jams are a preferred winter habitat for resident brook trout (*Salvelinus fontinalis*) and brown trout (*Salmo trutta*) (Cunjak and Power, 1986).

During high discharge events, rivers may overflow their banks. Although erosion and deposition occur within the flood plain, the reduction in water current velocity results in a net deposition of sediments to the flood plain. What proportion of the suspended sediment load is trapped by the flood plains or for how long is not known. Information on the retention of other sediment-bound pollutants, e/g. phosphorus and toxic chemicals such as PCBs, pesticide and heavy metals, in the flood plain is also lacking.

In wetlands, a reduction in water current velocity occurs due to the water dissipating laterally and the ponding effect of aquatic plants. This results in particulates settling out; for example, Hartland-Rowe and Wright (1975) observed a 95% reduction in suspended sediments as water passed through a wetland. Most (e.g., 81%) of the sedimentation apparently occurs on low natural levees adjacent to the stream (Johnston *et al.*, 1984). Sediment accumulation rates of 0.2 to 4.6 cm/yr have been reported for eastern United States (Lee *et al.*,1975) and similar rates can be expected for Ontario. Wetlands are perceived as being sinks for nutrients and contaminants. However, this is misleading for phosphorus, since phosphorus absorbed during summer may be released the following spring. Furthermore, in the case of wetlands receiving effluent inputs, there is a point of saturation in the retention of phosphorus (Kadlec and Kadlec, 1978). The fate of other sediment-bound pollutants, e.g., pesticides, PCBs and heavy metals, in wetlands require investigations.

Of the retention devices found along a drainage system, lakes and reservoirs are thought of as sediment traps. This is especially true for coarser sediment which are primarily deposited near the river mouth. However, lakes and reservoirs are not necessarily efficient in retaining smaller sediment fractions, i.e., silt and clay. This

is illustrated by an average retention of phosphorus of only 34% of the total phosphorus ranged from a −7% (output input) to 86%. In general, there is a decrease in retention with an increase in flushing rate, and an increase in depth. Most of the phosphorus transported into and out of reservoirs and small lakes is associated with sediments. For example, Rausch and Schreiler (1981) reported that 92% of total phosphorus inflow to a reservoir and 81% of total phosphorus outflow were sediment-bound.

Drainage basin size and reservoir hydrodynamics also have a strong influence on sediment trapping efficiency. Therefore, substantial retention of sediments may occur within the drainage system, at least temporarily. The relative importance of each mechanism will vary in the size, depth and turbidity of the stream or river, seasonal climate, geomorphological regime, and man's activities within the watershed.

Biological Effects

Sediment input may impact stream communities through a variety of direct and indirect processes, including reduced light penetration, smothering, habitat reduction and the introduction of absorbed pollutants (pesticides, metals and nutrients). Aquatic plants, periphyton, benthic invertebrates and fish are affected by sediment inputs.

With high turbidity resulting from suspended sediment concentrations, there is a decrease in light available for photosynthesis and hence a reduction in plant production. Algae and macrophytes may also be destroyed by the abrasive action of sediment or by becoming covered by a blanket of sediment. Pioneering plants found in crevices among rocks and on gravel substrate may succumb to siltation, whereas others such as rushes (*Juncus*), sedges (*Cyperus*) and shrubs (*Salix*) may colonize these areas if sufficiently stable. Since plants reduce the water current velocity, more sediment is deposited. This may accelerate plant succession, provided that the deposited substratum remains stable for a sufficient length of time for plant growth. However, dense growths of plants tend to be removed periodically by the scouring action of floods. Since plants (and detritus) are the basis of the food chain, a reduction in plant production will affect the food supply for stream invertebrates and, in turn, fish.

The nature of stream substratum is important in shaping the invertebrate community structure. In general, there is a decrease in the diversity and abundance of invertebrates with substrate in the order: cobble and gravel mud silt sand. The invertebrate fauna of cobble and gravel consists of many riverine specialists, including stoneflies, mayflies, caddisflies and blackflies, whereas the fauna characteristic of silt substrate includes aquatic worms (Tubificidae), midge (Chironomidae), burrowing mayflies (Ephemeridae) and clams(Unionidae and Pisidiidae).

Most studies indicate that the density of benthic invertebrates is severely reduced by sediment addition (Gammon, 1970; Hynes, 1971; Lenat *et al.*, 1981; Lemly, 1982). Usually, a change in the benthic community structure occurs, with a shift in dominance by silt-tolerant chironomids (Rosenburg and Snow, 1975; Dance and Hynes, 1980).

Barton (1979) found that sediment addition to Hanlon Creek, Ontario, as a result of highway construction had no short term effect on invertebrate density, although changes occurred in community structure. However, further observations by Taylor

and Roff (1986) revealed an increase in population and decline in diversity at 2.5 years post-construction. At five years post-construction, diversity rebounded, with a restructuring of the invertebrate community, especially the Trichoptera. In other instances, the community structure may be largely unchanged by sediment addition. For example, Lenat *et al.* (1981) reported that sediment inputs reduced the area of available rocky habitat, with a corresponding decrease in the benthic density, but with little change in community composition. During low flow conditions, in their study, stable sand areas supported high densities of invertebrates with a community distinct from that in rocky areas, but this community was washed away during high flows.

In certain situations, the detrimental effect of fine sediment on the biota may be masked by other factors. For example, Hawkins *et al.* (1983) reported that invertebrate densities decreased as percent fine sediment increased in shaded (forested) areas, but such a relationship was not evident at open sites due to increased primary production. In their study, density and biomass of fish were correlated with invertebrate abundance and inversely with the amount of fine sediment in shaded areas.

Lemly (1982) found that a reduction in the abundance of filter-feeding invertebrates was largely the result of disruption of feeding and filling of interstitial spaces. The size, quality (inorganic vs. organic) and quantity of suspended particulates affect the distribution and abundance of filter feeding invertebrates. Other benthic invertebrates may be directly affected by sedimentation through the adhesion of particles to their body surfaces and respiratory structures. Lemly (1982) found that the addition of nutrients (e.g., nitrates and phospates) in association with sedimentation resulted in the growth of the filmentous bacterium *Sphaerotilus natans* on both invertebrates and the substratum. Net formation due to overlapping filaments of *S. natans* augmented the accumulation of sediments, and the eventual blanketing and smothering of insects. Therefore, sedimentation and nutrient addition operated synergistically to eliminate a greater number of taxa than exposure to one pollutant alone.

For fish, current velocity, depth of water and shelter are important environmental variables (Hynes, 1971). The nature of the substratum is not important except with respect to spawning. However, eggs and fry are quite susceptible to siltation. Fingerlings and adult fish are quite resistent to temporary exposure to high suspended sediments concentrations. Nevertheless, under extreme conditions, suspended sediment concentrations may be lethal to fish. For example, a large fish kill was reported during a flood, which produced turbidites of 6,000 ppm and lasted for 15 days, and trout held in cages 2.5 km downstream of a gold dredging operation for 20 days suffered high mortality at turbidities of 1,000 to 25,000 ppm (Cordone and Kelly, 1961).

Suspended sediment concentrations seldom reach levels that are lethal to fish in natural systems, but short exposures to elevated concentrations of suspended sediments may reduce survival due to synergistic effects with other environmental stresses (e.g., increased temperature and decreased dissolved oxygen concentrations). Trout are not harmed by exposure to suspended sediment concentrations of 160 mg/L for short periods. The European Inland Fisheries Advisory Commission (1965) reported that suspended sediment concentrations of less than 25 mg/L have no effect on fisheries; good or moderate fisheries can be expected at concentrations of 25 to 80 mg/L; good fisheries are unlikely at concentrations of 80 to 400 mg/L; and

poor fisheries occur at concentrations greater that 400 mg/L. In the laboratory, Herbert and Merkens (1961) found that suspended sediment concentrations of 30 ppm had no effect on yearling rainbow trout, a slight effect at 90 ppm, whereas survival decreased at concentrations greater than 270 ppm.

Suspended sediments primarily harm fish through the physical abrasion of gill lamellae and gill mucous clogging causing anoxia (Noggles, 1978). At high suspended sediment concentrations, gills may become abraded, thickened and fused (Herbert and Merkens, 1961) Tolerance to high suspended sediment concentrations appear to be influenced by water temperature and perhaps prior sediment exposure or age of the fish. For example, Noggle (1978) reported LC50's for juvenile salmonids exposed to suspended sediments in excess of 30,000 mg/L in autumn, but less than 2,000 mg/L in summer.

Turbidity may also affect community structure through behavioural responses. In the Nemadji drainage system, Michigan, creek chubs (*Semotilus atromaculatus*) were abundant in the turbid mainstream channel and in turbid tributaries where predators were absent, but were absent from clear-water tributaries inhabited by brook trout (*Salvelinus fontinalis*). In laboratory studies, both species were more active and used overhead cover less often in turbid water than in clear water (Gradall and Seveson, 1982). However, in highly turbid water, creek chubs were most active, whereas brook trout were less active. Thus, turbidity may be an important isolating mechanism that promotes the production of creek chubs. Such an isolation mechanism also applies to the blackstripe topminnow (*Fundulus notatus*) which is absent from clear water in southern Ontario, but may be abundant in nearby turbid water (McKee and Parker, 1982).

Erosion and sediment deposition (as well as damming of streams) are blamed for the disappearance of Atlantic salmon (*Salmo salar*) from streams around Lake Ontario. In Duffin Creek, erosion from farmland filled interstices in gravel and cobble resulting in a loss of protective cover and a high mortality of Atlantic salmon fry introduced into the stream (McCrimmon, 1954). A large number of other studies also point to the negative impact of sediment on stream fish communities. For example, Saunders and Smith (1964) reported a 70% decrease in brook trout as a result of siltation due to sediment inputs from agricultural fields and removal of vegetation in drainage ditches (Figure 3). Trout populations recovered when siltation was reduced as a result of natural vegetation re-establishment between the fields and the stream, and within drainage ditches. Bowlby *et al.* (1987) found that brook trout biomass remained depressed and trout size was smaller immediately downstream of a highway construction site on Mill Creek, Ontario, ten years following construction. This was attributed to a reduction in habitat quality due to streambed erosion. Siltation in Hanlon Creek, Ontario, resulted in a reduction in the bottom-feeding fish population, i.e., mottled sculpin (*Cottus bairdi*) and white suckers (*Catostomus commersoni*), and an increase in the mid-water feeding fish population, i.e., blacknose dace *Rhinichthys atratulus* and creek chubs, (Taylor and Roff, 1986). Cleary (1964) observed that smallmouth bass (*Micropterus dolomieui*) nested and spawned with successful hatching of eggs during sporadic periods of high turbidity. However, he reported few fingerlings and poor fishing in streams that remained turbid for longer periods. Chinook salmon (*Oncorhynchus tshawytscha*) avoid turbid water for spawning (Sumner and Smith, 1939), whereas cutthroat trout (*Salmo clarki*) have

been reported to seek cover and stop feeding with an increase in turbidity (Bachmann, 1958).

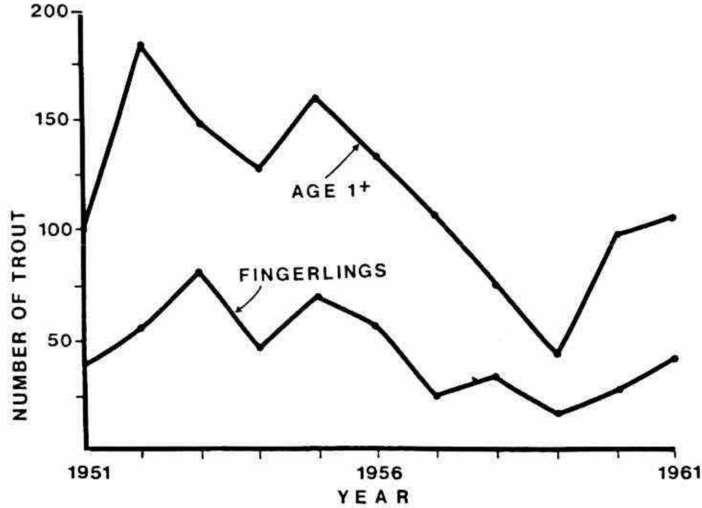

Figure 3. Effect of heavy siltation in 1959 on brook trout population (Saunders and Smith, 1973).

In most studies, it is difficult to distinguish between changes that occur in the fauna as a result of siltation as opposed to changes in other parameters, such as in water temperature, hydrology and input of nutrients and allochthonous organic matter (mainly autumn-shed leaves that fall into the stream - an important source of food for invertebrates). However, Gammon (1970) reported on a study of Dean Creek, Indiana, in which sediment was the primary factor that was different downstream of a quarry compared with upstream reaches. SInce sediment input from the quarry was light yellow in colour and contrasted sharply from the dark instream material, it was easy to visually gauge the degree of sedimentation that occurred within the stream.

Under conditions of low sediment input and low flows, most of the sediment was deposited in pools and riffles immediately downstream from the quarry (Gammon, 1970). Under heavy sediment input, the pools became filled with sediment resulting in a decrease in fish standing crop in these areas (Figure 4). When the sediment was flushed from these pools the following spring, recolonization by the fish was only about 50% of that observed in pools immediately upstream of the quarry. Invertebrates were also affected by the sediment. When suspended sediment concentrations were about 40 mg/L above upstream levels, a 25% reduction in the invertebrate standing crop was observed, whereas at concentrations of about 120 mg/L above upstream levels, a 60% reduction occurred. Experimental addition of sediment to the stream resulted in an increase in invertebrate drift downstream in proportion to resultant suspended concentrations.

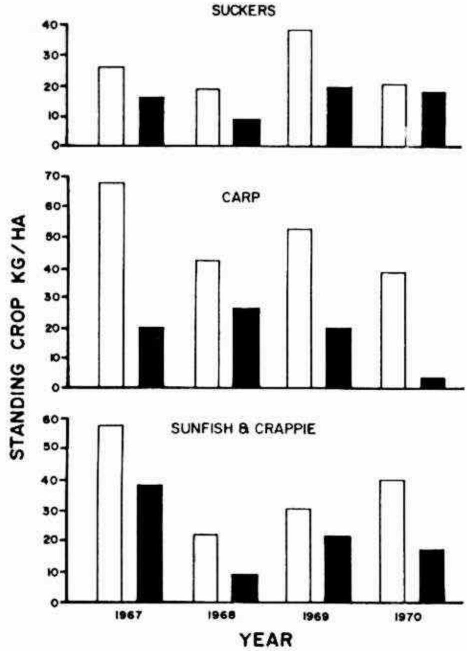

Figure 4. Estimated mean fish standing crop above (clear) and below (solid) a quarry (modified from Grammon, 1970).

In another study, Waters (1982) observed a decrease in the production of the amphipod *Gammarus* (Figure 5) in Valley Creek, Minnesota, as a result of siltation caused by construction and agriculture activities upstream. *Gammarus* was the principal prey of brook trout in Valley Creek, and a decrease in its production resulted in a decline in trout production. Also, poor year class strength of age 0 trout in 1971 suggested that siltation affected spawning success (Figure 5). Filling in of interstices in gravel reduced the flow of water and oxygen to fish ova, whereas adhesion of silt particles to the chorion of ova may also interfere with development (Gibbons and Serlo, 1973). As illustrated in Figures 6 an 7, these processes contribute to increased mortality of the eggs. Sedimentation also impacts on the invertebrate fauna living within the streambed (the hyporheic fauna) and, as previously mentioned, filling in of interstices in gravel and cobble many increase predation of fry through a loss of cover in which to hide (MacCrimmon, 1954).

Erosion of farmland, channelization of streams, and trampling of stream banks by cattle have increased the suspended sediment load of streams and generally have resulted in a lower diversity and abundance in stream communities throughout North America (Chapman and Knudsen, 1980; Schlosser, 1982; Kaufman *et al.*, 1983; Ontario Ministry of the Environment, 1983; Prott *et al.*, 1986). Modification of headwater streams by channelization and agricultural drainage is considered a major factor responsible for shifts in large river fish communities from insectivore-piscivore species (e.g., trout) to omnivore and herbivore-detritivore species (e.g., minnows)

(Schlosser, 1982). However, natural areas left within these altered habitats often support a healthy and diverse biotic community (March and Luey,1982).

In southern Ontario, Bowlby and Roff (1986) reported that groundwater inflow, food (stream invertebrates), summer maximum water temperature, piscivorous fish,

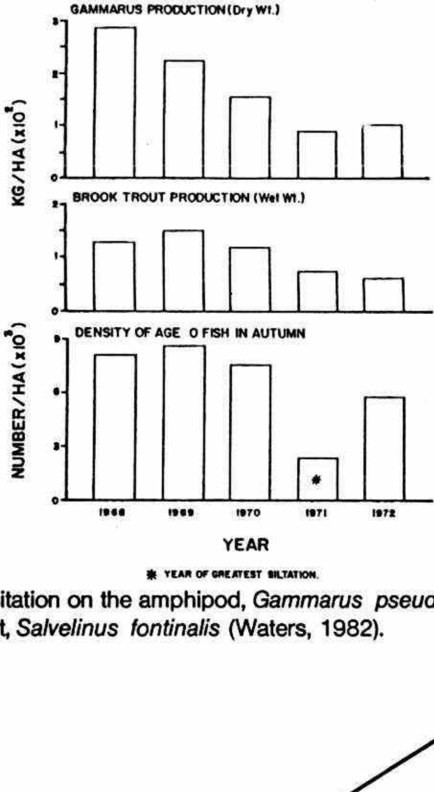

Figure 5. Effect of sitation on the amphipod, *Gammarus pseudolimnaeus,* and brook trout, *Salvelinus fontinalis* (Waters, 1982).

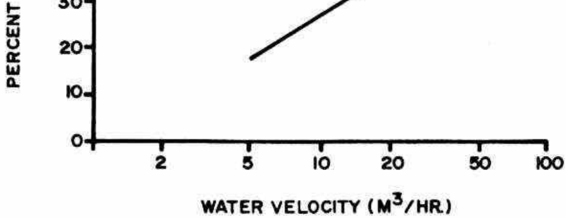

Figure 6. Effect of flow of water through redds on survival of trout eggs (modified from Cobble, 1961)

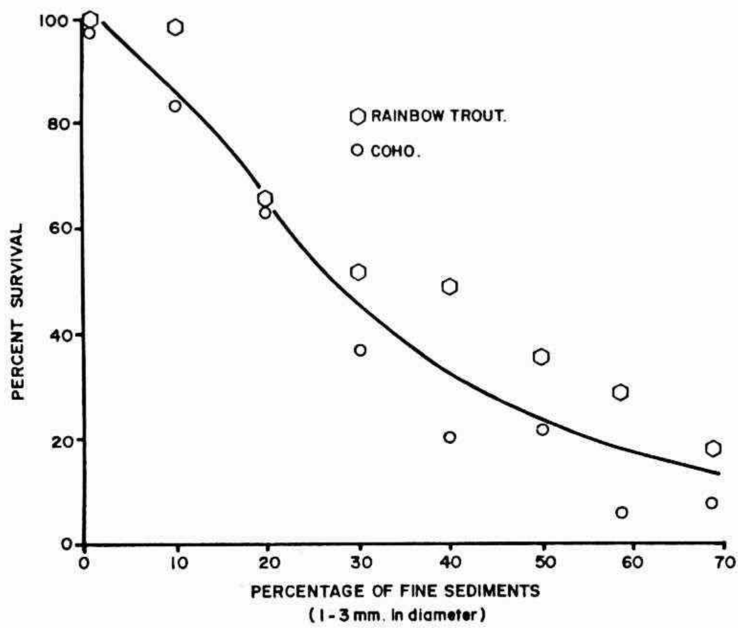

Figure 7. Influence of fine sediments in redds on survival of rainbow trout and coho salmon eggs (modified from Gibbons and Salo, 1973).

pool area and overhead cover were the major limiting factors for trout in 20 streams. However, Barton *et al.* (1985) found that the only environmental variable which clearly distinguished between trout and non-trout streams was weekly maximum summer water temperature. In their study of 30 southern Ontario streams, those streams which had trimean (a value based on the maximum and range) weekly maxima temperatures less than 22°C had trout, whereas warmer streams had at best only marginal trout populations. (Neither of these studies investigated the effect of siltation on spawning.) Hynes (1969) believes that, before the arrival of settlers from Europe, trout probably occurred throughout southern Ontario. However, with the removal of riparian vegetation (e.g., for agricultural purposes), streams were exposed to more solar radiation, causing water temperatures to increase often above the tolerance limit of 25°C for brook trout. Thus, any effort to manage the fishery is southern Ontario streams must focus on control of water temperature, as well as sedimentation.

Sediment loads are ten to 100 times greater for urban and cultivated land than forest or idle pasture. Suspended sediment concentrations increase with discharge, most of the sediment being transported during high discharge events. Substantial retention of sediment may occur within the drainage system, at least temporarily, depending upon the nature of retention devices present and the intensity, duration and frequency of high discharge events. It has been long known that siltation alters the aquatic environment by screening out light, by changing heat radiation, by changing the nature of the substratum and by transporting and depositing organic

matter and toxic contaminants, which create unfavourable conditions within bottom sediments. For example, decomposition of organic matter within the sediment may create an oxygen demand with the production of noxious compounds such as hydrogen sulphide, ammonia and methane (Ellis, 1936). Sedimentation results in: a reduction in the population and/or diversity of fish and stream invertebrates; a loss in angling opportunities; poorer water quality; and increased pollutant loads to lakes. The negative impact of sediments in rivers and streams is confounded by interactions with other environmental stresses, particulary increased water temperature, nutrient loading, reduced oxygen concentration and unstable water discharge regime.

In natural ecosystems, control of soil erosion is achieved by: the canopy and forest floor, which intercepts and reduces the kinetic energy of raindrops; accumulation of organic material in soil surface layers, which enhance infiltration and percolation of water; roots, which bind the soil together, especially along stream banks; and debris jams in stream channels, which help regulate streamflow and retard erosion and transport of particulate material (Likens, 1984).

Thus, remedial measures to alleviate the impact of sediments on streams should consist primarily of the practice of soil erosion control on farmland, e.g., conservation tillage, and the maintenance of streams in as natural a condition as possible, i.e., bordered by riparian buffer strips and harbouring debris jams.

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Water Quality of Streams in Southwestern Ontario

Denis Veal, Brian Chambers, John Westwood

The quality of surface waters in Ontario varies greatly, depending on what part of the Province you are in. Sections of the shield are affected by acid rain and heavy metals. Various parts of the Great Lakes are affected by phosphorous, turbidity, bacteria, PCBs, mercury, mirex, toxaphene, and many other contaminants. The inland streams are affected by turbidity, nutrients, bacteria, elevated temperatures, and so on.

In an effort to properly manage water quality in the Province, the approaches have had to change over the years, as new information comes to light. Prior to the 1970's, the focus was on "point source control". During the 1950's and 1960's, numerous sewage treatment plants and industrial treatment facilities were constructed in order to remove solids and oxygen consuming wastes that would otherwise cause impairment in receiving watercourses. In the 1970's, the Pollution From Land Use Activities Reference Group (PLUARG) studies revealed that non point pollution was largely responsible for excess phosphorus loadings to the Lower Great Lakes, and water management agencies then had to address agricultural pollution.

It would appear that throughout the 1980's, there will be a strong focus on "hazardous contaminants". The Municipal and Industrial Strategy for Abatement (MISA) of the Ontario Ministry of the Environment is specifically designed to reduce the loadings of "toxics" to the environment.

Parameters of Concern

Water quality management is now very complex. Technical people in the field of water quality management have had to specialize in order to carry out their job competently and professionally. We now have dioxin specialists, PCB specialists, and many other specialists who cover a narrow field of water quality management. With all the special attention and publicity given to the many new and complex toxic contaminants, however, we must not lose track of the fact that *the old, conventional parameters are still a major concern.* Many of our inland streams in Southern Ontario cannot be fully utilized and enjoyed because they are too warm to support our favourite fish, they are too full of bacteria for safe swimming, or they are choked with unsightly algae.

Scope of This Paper

The authors of this paper are water quality "generalists". From time to time, we become involved in specific toxic contaminants. But toxic contaminants are *not* the subject of this paper. The subject of this paper has to do with key selected *conventional* water quality problems that never seem to go away. Not only do they

seem to go away, but they seem to defy problem correction. The general stream of problems of nutrients, bacteria, turbidity and suspended solids, and stream warming, remain with us despite some efforts to address these problems.

In this paper, we simply want to look at four conventional stream parameters (suspended solids, phosphorus, nitrate, fecal coliform bacteria), and provide some insight into management success and future management possibilities.

Water Quality Evaluations

The Ontario Ministry of the Environment, as well as other agencies, typically have two approaches in assessing water quality. One approach is to plan and carry out detailed studies which are designed to evaluate a specific problem, either potential or existing. The other approach is to simply "monitor" water quality over a period of time, and use the monitoring data to show both the status of water quality in selected areas, and water quality trends. This particular paper uses some water quality monitoring data in Southwestern Ontario, to illustrate good water quality, and also to illustrate the degree of water quality impairment from agriculture, and from urbanization.

The Ontario Ministry of the Environment monitors the water quality of inland streams at over 600 locations through the Province. At each of these locations, water quality measurements are typically made on a monthly basis. Some of the "monitoring locations" have over 20 years of record.

Variations in Water Quality

Within the field of "conventional" water quality parameters, we have the benefit of having studied practically the full range of Ontario's stream quality. Within Southwestern Ontario, we have some beautiful trout streams in Grey and Bruce Counties. Many of these watersheds are still well forested, and have not yet been degraded by agricultural drainage and development. In contrast, we also study water quality on the Lake Erie watershed, where agricultural activities have severely degraded general stream quality. The examples of water quality that are presented below illustrate some of the best and some of the worst water quality in the Province. The good water quality in Southwestern Ontario must be protected against the biggest threat of agriculturalization. The poor water quality must be improved.

Comments on Specific "Conventional" Water Parameters

If we were to assess the general water quality of our inland streams, and were allowed to utilize only five conventional parameters, we would likely utilize the following:

1. temperature
2. suspended solids
3. phosphorus
4. nitrate
5. fecal coliform bacteria

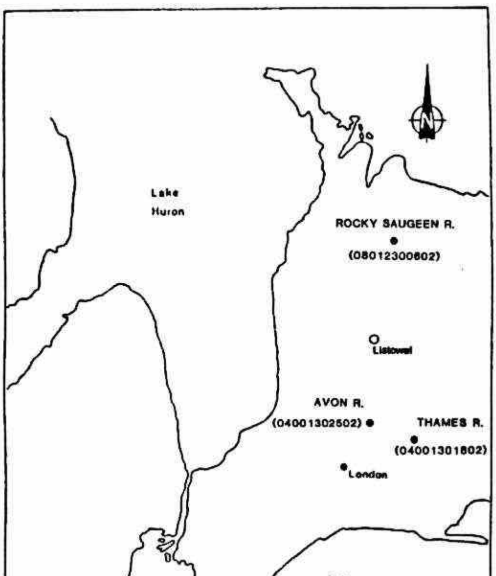
For this paper, we have reviewed the latter four parameters. Temperature is not included because of the difficulty of interpretation.

For the period of record, the four parameters were evaluated, at three water quality monitoring sites (Figure 1). The site on the Rocky Saugeen River (MOE #08012300602) reflects good quality water in an area where point sources wastes are absent and where non point pollution is small because of limited agricultural development.

The Thames River site (MOE #04001301802) reflects stream quality in an area that is intensively agriculturalized. Field tiling to improve drainage is common, row cropping (corn, beans) is common throughout the watershed, and livestock density is high. The sewage lagoons at Tavistock constitute the only significant point waste source on the watershed. However, the lagoon system discharges for only a couple of weeks in each of the spring and fall periods, and the overall impact on water quality is minor relative to the agricultural impact.

The Avon River site (MOE #04001302502) is located on a watershed which is agriculturally similar to the Thames River site. However, the Avon site is downstream of the continuous discharge from the Stratford Sewage Treatment Plant (STP). The

FIGURE 1: LOCATIONS OF WATER QUALITY MONITORING STATIONS



Stratford STP provides high quality treatment, including activated sludge, and filtration, a high degree of phosphorus removal, and effluent chlorination. This degree of treatment is necessary because of the small size of the Avon River. During most, if not all summers, under low flow conditions, the effluent flow exceeds the dilution flow in the Avon River (Ontario Ministry of the Environment, 1984).

Methodology

In order to operate the stream quality monitoring program, local Conservation Authority staff collect the water samples, and submit them to the Ministry of the Environment, London Laboratory. Analytical methods consist of Standard Methods (APHA, AWWA, WPCF, 1985), or variations that have been adopted by the Ministry. All of the data generated by this monitoring program are computerized by the Ministry of the Environment.

Suspended Solids

Figures 2A, 2B and 2C illustrate all of the individual suspended solids (ss) concentrations that have been measured at the three monitoring sites over the period of record. The Avon and Thames sites had similar levels of suspended solids, with

FIGURE 2A: ROCKY SAUGEEN R. SUSP. SOLIDS

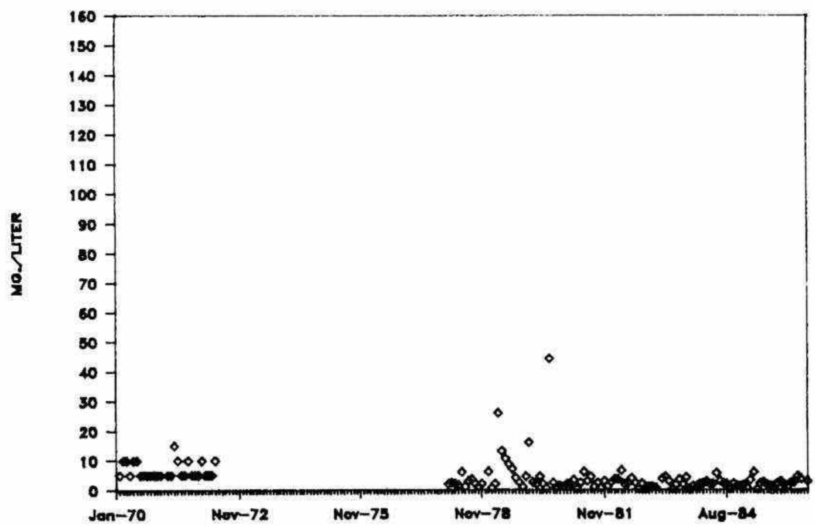


FIGURE 2B: THAMES R. SUSP. SOLIDS

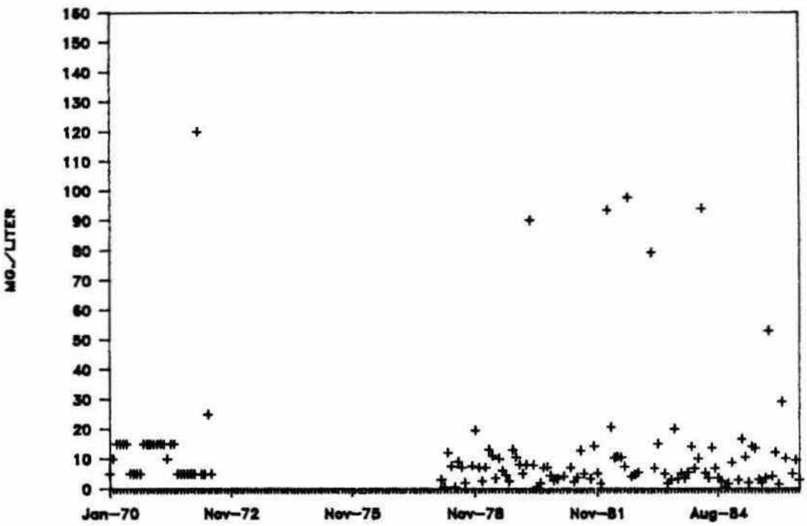
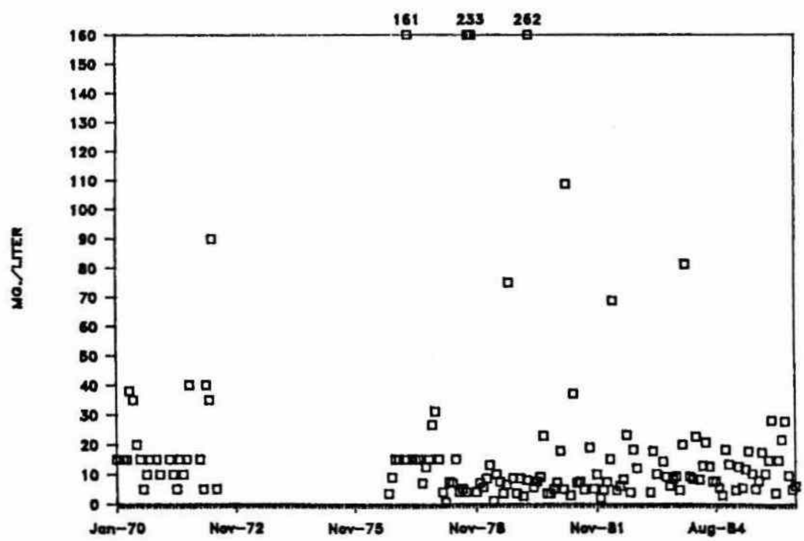


FIGURE 2C: AVON R. SUSP. SOLIDS



individual values frequently exceeding 50 mg/l. The Saugeen site was very different. The large majority of samples from the Saugeen showed ss levels below 10 mg/l, with the highest sample in the 40 - 50 mg/l range.

These data show the large impact of erosion resulting from agricultural land use.

Phosphorus (P)

Figures 3A, 3B, and 3C illustrate phosphorus. While the Ministry of Environment does not have a single definitive objective for stream phosphorus the "Blue Book" (Ontario Ministry of the Environment, 1984) suggests that stream phosphorus should be below 30 ug/l. Of the three rivers studied, only the Rocky Saugeen meets this "objective" most of the time. The Thames site is usually in violation of the objective, and the Avon site would appear to be in violation practically all of the time.

The Avon is higher in phosphorus than the Thames because of the Stratford STP effluent. However, because of phosphorus improvements in the STP effluent, the Avon river phosphorus quality is now approaching the Thames phosphorus quality. Efforts are now under way (Ontario Ministry of the Environment, 1984) to achieve an STP effluent with 0.1 mg/l phosphorus. If and when this is achieved, the phosphorus concentration in the STP effluent will have decreased two orders of magnitude within 15 years. With a 0.1 mg/l phosphorus effluent, the Stratford STP will frequently be diluting the Avon River with regard to total phosphorus.

The above scenario is of considerable interest. There is now good evidence developing that well operated, sophisticated STPs can match or exceed receiving river quality with regard to some critical parameters such as phosphorus. Obvious-

FIGURE 3A: R. SAUGEEN R. TOTAL PHOSPHORUS

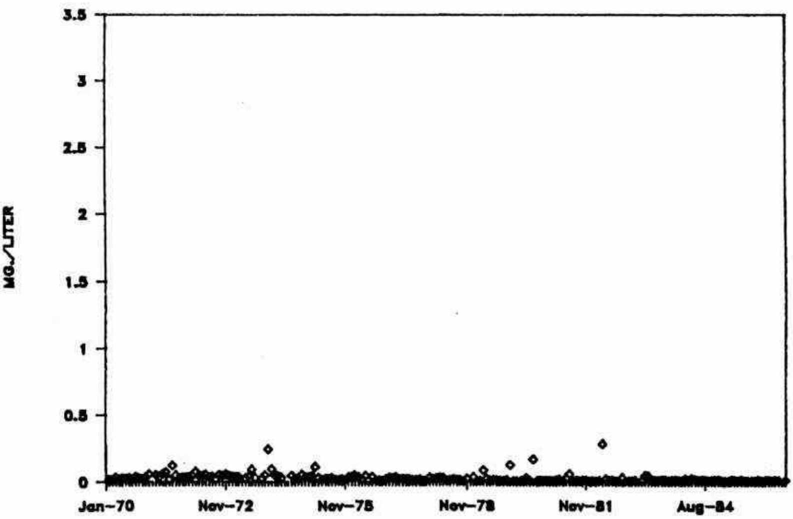


FIGURE 3A

FIGURE 3B: THAMES R. TOTAL PHOSPHORUS

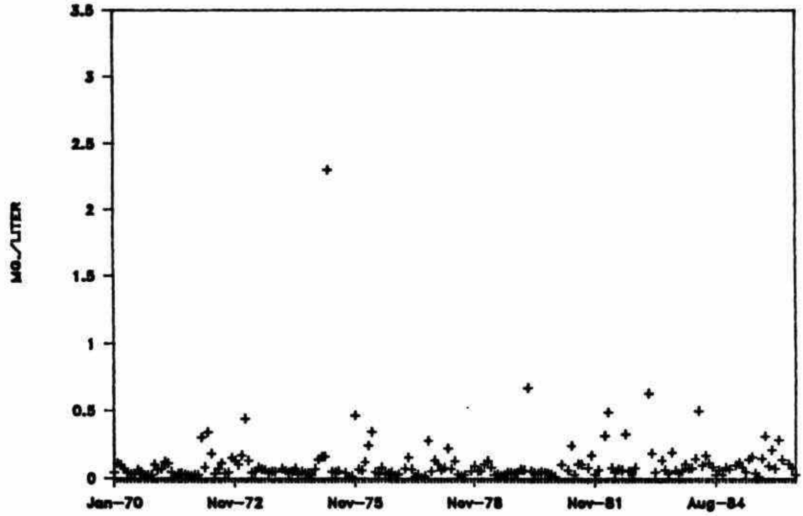
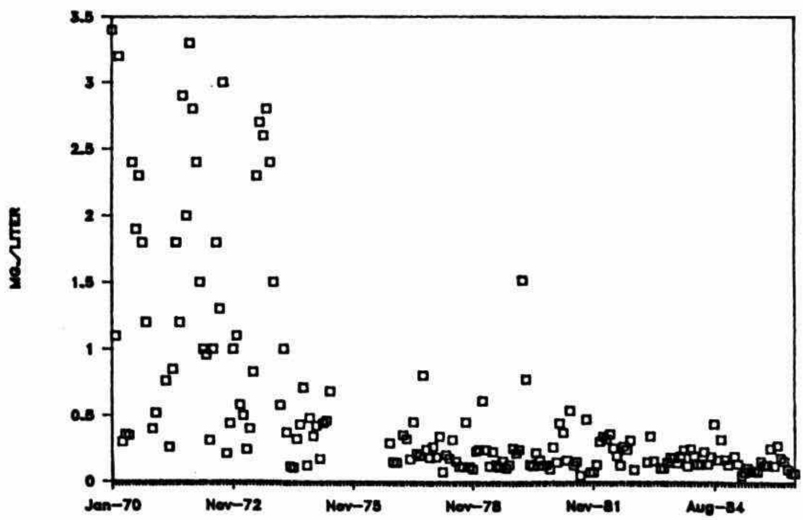


FIGURE 3C: AVON R. TOTAL PHOSPHORUS



ly even a sophisticated plant could not match the quality of a good trout stream such as the Rocky Saugeen, and for this reason efforts have been made to keep point sources out of high quality streams. Nevertheless, for many of our agriculturally impacted rivers, urbanites in Stratford and elsewhere are now starting to question the adequacy of agricultural pollution control on their own watersheds.

Nitrate

Figures 4A, 4B, and 4C illustrate nitrate concentrations at the three river monitoring locations. Nitrate concentrations in the Rocky Saugeen are consistently low. The other two river sites exhibit concentrations that are much higher on average, and that fluctuate greatly from one period of time to the next.

It is of interest to note that the nitrate levels in the agricultural watershed (Thames site) are very similar to those in the agricultural plus urban watershed (Avon site). It would appear that the urban impact of Stratford is very much masked by agricultural activity on the Avon River.

It is always difficult to provide useful comments on the significance of nitrate levels that are typically found in Southwestern Ontario streams. The Ministry of the Environment does not have ecological based nitrate criteria. There is, however, a human drinking water objective of 10 mg/l. Theoretically, it is desirable to keep a watercourse below the 10 mg/l objective in case a future water supply is required.

Because of changing agricultural practices, nitrate levels in some of our agricultural streams have increased (Gartner Lee Associates Limited, 1986). Similarly, increasing nitrate levels in sensitive aquifers in various parts of North America have

FIGURE 4A: R. SUGEEN R. NITRATE

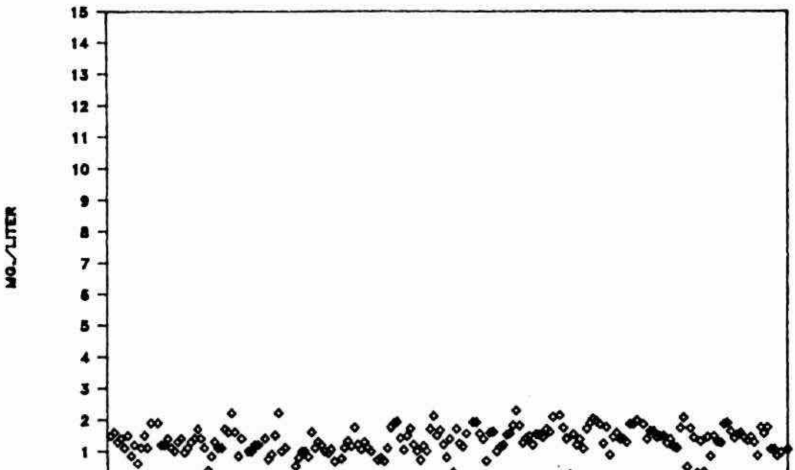


FIGURE 4B: THAMES R. NITRATE

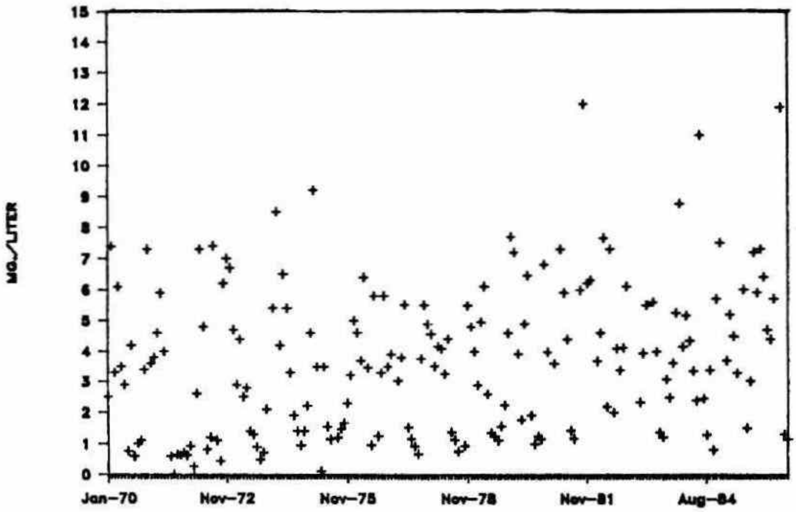
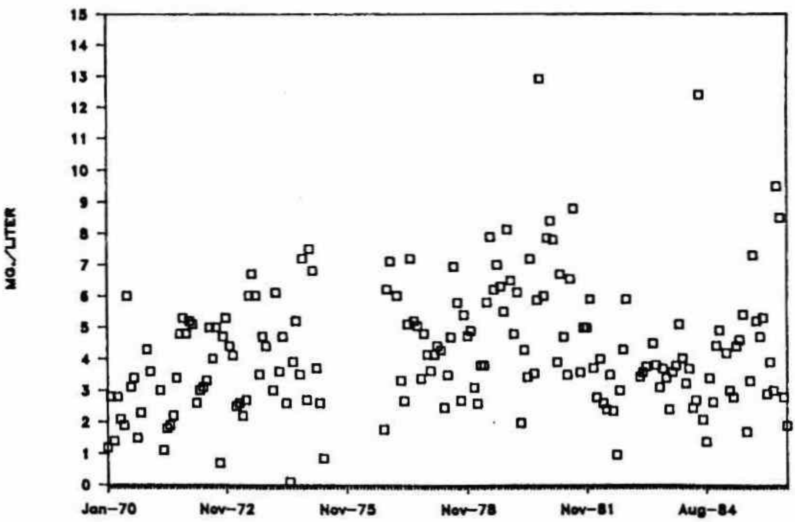


FIGURE 4C: AVON R. NITRATE



been documented (Hallberg, 1986). With both surface waters and water supply aquifers showing evidence of periodically exceeding safe drinking criteria, it is likely that nitrate contamination will become more of an issue in the future.

Fecal Coliform Bacteria

Figures 5A, 5B, and 5C illustrate fecal coliform bacteria.

Unlike the other three parameters discussed, the concentrations of fecal coliforms on the Rocky Saugeen do not appear to "stand out" from the other two river sites. In general, there would appear to be a gradation in fecal coliform quality between the three rivers. The Rocky Saugeen would appear to be the best, the Thames in the middle, and the Avon the worst.

The Ministry of the Environment's swimming criteria for fecal coliform (fc) bacteria is 100 fc organisms per 100 ml, based on the geometric mean of a number of samples.

Future Management

Good water quality management is not easy to do. If it were easy, we would not have the degree of water quality problems we now have.

Under Ministry of the Environment policy, as outlined in the "Blue Book" (Ontario Ministry of the Environment, 1984), the Provincial philosophy is to keep clean waters clean ("Policy 1"), and to upgrade polluted waters to the Provincial Objectives ("Policy 2"). These are logical, common sense policies. The effective implementa-

FIGURE 5A: R. SAUGEEN R. FECAL COLIFORM

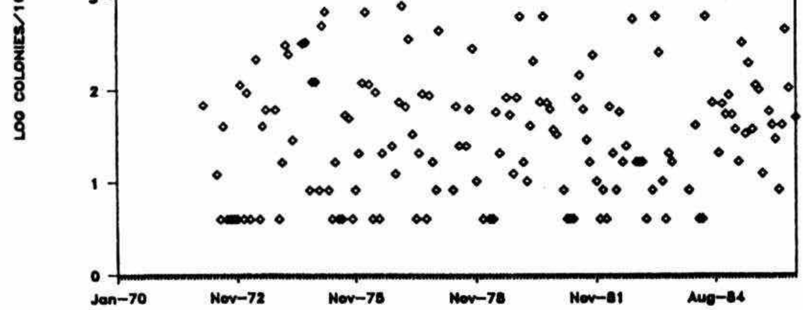


FIGURE 5B: THAMES R. COLIFORM

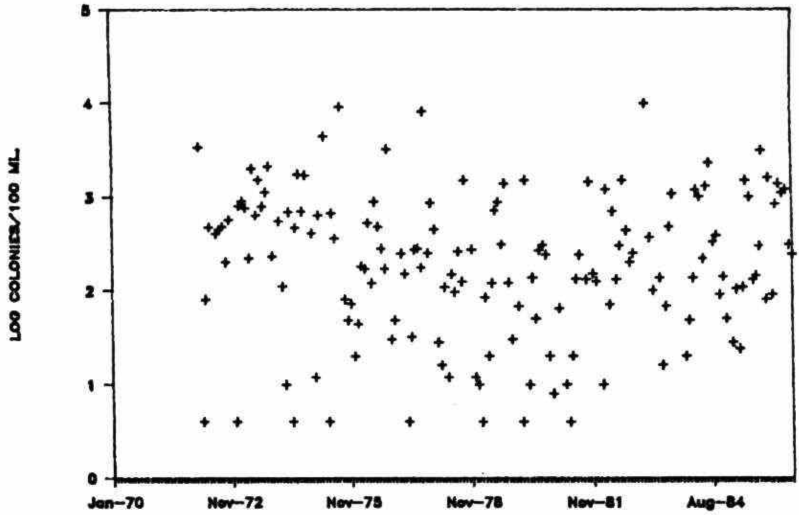
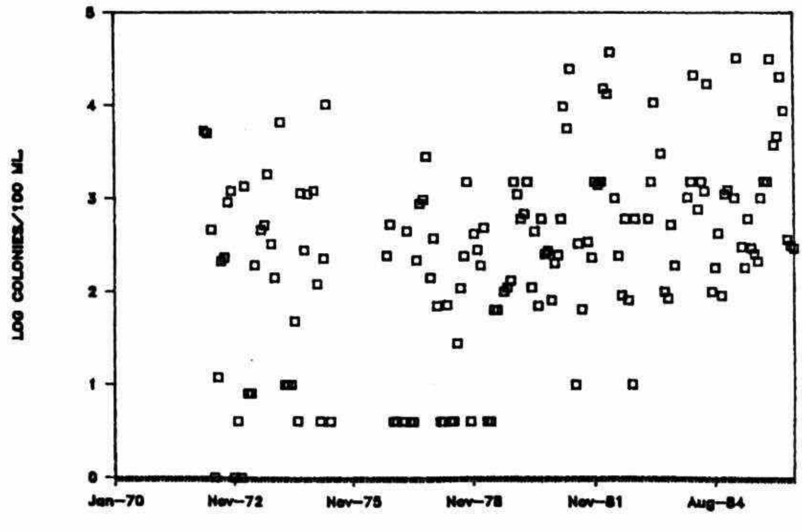


FIGURE 5C: AVON R. FECAL COLIFORM



tion of these policies, however, presents a good challenge to all of us working in the field of water resources management.

The management of pollution caused by point sources is much easier than the management of pollution caused by non point sources. A classic example of this is Lake Erie. Lake Erie, 20 years ago, had much greater algae problems than it has today. With the reduction of phosphorus in detergents, and phosphorus removal at sewage plants, the trophic status of Lake Erie quickly improved.

Even in the field of toxic waste management related to point sources, the near future looks very promising. Ontario's new Municipal and Industrial Strategy for Abatement (MISA) will effectively reduce toxic emissions from point sources. The MISA program, along with the new thrust of environmental enforcement, will go a long way toward addressing the remaining problems related to point source pollution.

But what will we do to effectively manage non point activities resulting in stream warming, nutrient enrichment, turbidity, and bacterial contamination? It is clear from Figures 2 - 5, and from numerous pieces of literature, that these problems in our inland streams never seem to go away because of the difficulty in managing agricultural pollution. We also know that when normal agricultural activities intensify on a watershed, major water quality deterioration will result.

Many sensitive, high quality trout streams in Grey and Bruce counties, as well as other parts of the Province, are in jeopardy. There are only two ways of maintaining these high quality waters with the Provincial Water Quality Objectives. One way is to keep intensive agriculture out of these areas. The second is to develop and implement improved environmental management of farms.

In the United States, the 1985 "Farm Bill" (Benbrook, 1986) provides an exciting and innovative approach to integrated land and water management. Farmers are strongly encouraged, through financial incentives, to concentrate their farming on those acreages that produce prime crops, and result in minimal water quality impact. The Farm Bill is only a start toward what is needed in the future in the overall field of integrating land resource and water resource management; but the Farm Bill provides a good example of a good start.

In order to protect sensitive and important high water quality areas, we need some leadership and some new approaches. Perhaps some water resource environments are too sensitive to tolerate any development. Other areas may require strict enforcement of non point polluters.

Non point pollution has already resulted in extensive water quality "violations" in many parts of southwestern Ontario. If agriculture advances northward into the sensitive trout stream areas, similar violations will materialize in these new areas, unless some new resource management approaches are developed and implemented. This presents a major challenge for the tough and famous.

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Microbiological and Toxicological Studies of Streams

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Abstract

A summary of effects which occur when a pollutant enters a stream is presented. In order to try to understand the events which occur after a pollutant enters a stream or river a series of studies listed below were undertaken, and are described. Studies on the transport and survival of bacteria in fresh water systems; studies on the evaluation of the role sediments play in the survival and multiplication of bacteria; and the development of a battery of tests which can be used to evaluate stream or river microbiological, biochemical and toxicant loadings so that areas of concern within a fluvial system can be prioritized.

Introduction

Rivers and streams are dynamic living mobile masses of water which are continually being renewed, and similar to snow flakes no two samples of water are identical. Pollutants rarely enter rivers and streams at a constant rate, except from planned discharges such as sewage treatment plants and industrial discharges, and even here there is tremendous variation in the nature and concentration of the discharged contaminant.

A single micro or mega pollutant spill of chemical or fecal matter upon entering a stream or river undergoes a variety of events. As the pollutant slug enters and is transported downstream, many factors come into play such as, stream flow rate and volume, photodegraduation, U.V. light sterilization, particulate matter size and concentration, adsorption or absorption of the pollutant to settling particles and the grazing activity of the microbiota.

Several scenarios can occur with single spills as well as continuous inputs. One event which occurs when the pollutant slug is a soluble chemical, is for the pollutant slug to be transported downstream, continually being diluted and sedimented until there is no further trace of the event in the water column. This implies once the pollutant slug has passed any point no record of its existence would be found in the water column one or two hours later. Another series of events which occur when the pollutant is a hydrophobic viscous chemical, e.g. oil, is for the pollutant to partially act as a floating slug of water, as well as, contaminating plant life, stream banks, debris and sediments as it flows downstream due to its viscous nature. These contaminated areas serve as long-term sporadic inoculum sites. Since biodegradation of this type of contaminant is relatively slow, one time input of these chemicals have long term and great distance effects. In the third scenario, fecal material from cattle, pigs, wildlife, etc. are the pollutant. The fecal particles contaminated with bacteria can float with the whims of the currents, can settle into the immediate sediments

for recycling and resuspension, can get entangled and disentangled with vegetation, shorelines and debris until finally the particles and bacteria settle into the sediment or are grazed upon as food.

The problems we face are that we do not know how far, how quickly and at what concentrations these pollution slugs move. When these pollution slugs become part of the sediment, we do not know how far this occurs from the input, at what concentrations is can be found, how long it will stay in the sediments before biodegradation takes place, or it is buried or it is recycled to the water column as a new product or the same chemical. We also do not know how long the various bacteria of fecal origin can survive in various water bodies and sediments.

In order to try to understand the events which occur when a pollutant enters a stream or river, our laboratory has undertaken the following studies:

1. Studies on the transport and survival of bacteria in fresh water systems;
2. Evaluation of the role sediment plays in the survival and multiplication of bacteria, and
3. Development of a battery of tests which can be used to evaluate stream or river microbiological biochemical and toxicant loadings so that areas of concern within a fluvial system can be prioritized. In this article, descriptions and discussion of some of these studies are presented.

Microbial Transport and Longevity Studies

Stream transport studies were performed using the tracer organism *Serratia marcescens* (Dutka and Kwan, 1980). This organism produces a typical maroon red colony on nutrient agar and is a member of the family Enterobacteriaceae to which coliforms, fecal coliforms and *Salmonella* also belong.

Two stream studies were performed, one in the summer (July) and the other in the fall (October-November). A 200 litre broth culture of *S. marcescens* was used to inoculate the stream, at chosen up stream sites. Gauze collection pads (Dutka, 1978) were suspended in the stream at various selected sites and were collected after varying immersion periods. The five-fingered gauze pads were dismembered and deposited in various selected enrichment broths and, after incubation, loopfuls of the broth were transferred to tryptone soya agar plates containing an antibiotic mix. Growth of the red antibiotic resistent *S. marcescens* after a 48–72 hr. incubation, indicated the positive retrieval of the organism from the stream.

In the summer study the tracer organisms were isolated after 3 days at a site 5.5 km from their input and they continued to be isolated here for a periods of 8 days. It was estimated that it took the organism between 48 and 72 hours to travel 5.5 km. Stream flow velocities indicated that the tracer organisms should have reached the site in 29 hours.

In the October-November study, water movement rates indicated that only 34 hrs would be required for water masses to move through the 20 km distance length of this study. However, it took 7 days of travel time before *S. marcescens* was isolated at the last station. During this study the tracer organism was isolated for a period of 22 days at various sampling sites.

These data indicate that bacteria foreign to the stream environment can live for a least 22 days. The data also indicate that bacteria do not form a homogeneous sys-

tem with a water body; instead they act as particulate matter which is sedimented or absorbed to larger floating particles or caught in eddys, then released, or resuspended from the sediment into the main water flow to be carried further downstream. The data from this study suggest that no predetermined movement rate for water borne bacteria can be established.

Longevity of a bacterium is influenced by many factors, such as water temperature, sunlight (Dutka, 1984), grazer level, pH, oxygen level, organic content, toxicants, flow rate and physical environment. Since bacteria in nature can be free-floating, attached to fine particles or embedded in a nutrient mass, it would be expected that survival times might vary. In an attempt to evaluate potentially different survival periods, two studies were undertaken to estimate the survival of free-floating, attached and buried bacteria. These studies were performed by placing membrane filter chambers (McFeter and Stuart, 1972) in a fresh water pond and Burlington Bay (Dutka and Kwan, 1983).

In the first study, May to August, overnight broth cultures of *Escherichia coli, Klebsiella pneumoniae, Salmonella thompson* and *Streptococcus faecalis* were each inoculated (2 mL) into 200 mL of autoclaved Lake Ontario water. The inoculated lake water was dispensed in 100-mL portions into the membrane filter chambers; two chambers were prepared for each organism. The eight inoculated chambers were tested for baseline density levels and then placed on top of the sediment in a freshwater pond. After 21, 42 and 84 days, the chambers were retrieved, samples were collected from the chambers by means of sterile syringes, and the chambers were returned to the experimental sites. During sample collection the chambers were agitated in order to resuspend the bacteria that might have become attached to the inner chamber walls and membrane.

For the second study, November to May, the McFeter and Stuart membrane filter chambers were modified by enlarging the capacity from 100 mL to 3000 mL. In attempting to mimic natural occurrences, it was believed important to increase chamber capacity to provide greater surface area (chamber walls and chopped agar) on which bacteria might attach and would allow movement of the chopped agar so that surface bacteria might become surrounded with nutrient masses. The organisms *E. coli, K. pneumoniae, S. marcescens, S. faecalis* and *S. thompson* were evaluated during the winter longevity study. To each chamber was added 1 L tryptone soya broth augmented with 10 g beef extract and 1 L solidifed chopped tryptone soya agar augmented with 30 g beef extract. Each chamber was inoculated with approximately 150 mL of overnight broth culture of one of the organisms, and the remaining space in each chamber was filled with phosphate buffer. After the contents of each chamber were mixed and allowed to briefly acclimatize, baseline densities for each organism were established. The chambers were then suspended in Burlington Bay, 5 metres above the bottom and 2.5 metres below the surface. The chambers were retrieved 162 days later and tested for microbial populations.

Results from the first summer study using lake water diluent, indicated that the four organisms, *E. coli, K. pneumoniae, S. thompson* and *S. feacalis*, were all able to survive the 84 day study period. Similar results were obtained from the winter study. All the test organisms, *E. coli, K. pneumoniae, S. thompson, S. faecalis* and *S. marcescens*, easily survived the 162 day immersion period.

This survival-longevity study, indicates that fecal and tracer organisms can easily survive an immersion period of 162 days. Thus any waterway, beach, lake or pond which has been subjected to fecal pollution, even once, can remain a source of pathogenic bacteria for a long time. Disturbances such as heavy rainstorms, swimmers or dredging activities could at any time recycle pathogenic bacteria throughout the water column and into humans or animals directly or indirectly through breakdown in potable water treatment systems.

The bacterial movement and longevity study data, indicate that a single upstream inoculum of fecal material can and does have a long-term downstream effect. We firmly believe that the distance travelled by the indicator bacteria and the survival times displayed by the test organism greatly underestimate natural conditions.

Sediment-Bacterial Relationships

Our bacterial longevity studies were extended to evaluate the relationship between microbial community structures and microbial densities in sediments and contaminants in sediments. Over 100 surface sediment samples from the St. Lawrence River Basin were examined for various microbial physiological types and densities (Rao and Mudroch, 1986). These organisms were correlated to the concentrations of trace elements (Ni, Co, Cr, V, Cu, Pb, Zn, As, Fe, Mn, and Ti) and nutrients (P and organic matter). Results of these investigations indicated that there was bacterial population inhibition in the sediments due to the presence of certain toxicants. Generally, we observed in these sediments high and low microbial density areas with the lower microbial density areas being associated with areas having high concentrations of trace elements.

Data from these studies were also supportive of the hypothesis that the availability of organic matter (nutrients) for complexation with trace metal contaminants is dependent on microbial density and activities. Thus microbial community structure, microbial density and microbial activity rates in sediments can be used to provide valuable insights into the contaminant status of sediments and the stream.

From these sediment-contaminant-microbial population studies we have been able to confirm that microbial survival and reproduction in sediments are variable from site to site. This variability is due in part to the contaminant status of the sediments. These data suggest that trying to predict the survival and recycling of microbial inputs into a water course for modeling aspects is a very complex proposition.

Battery of Tests Approach

In research investigations or routine monitoring of waters and sediments, a variety of techniques have been used to designate waterbodies or sediments that are degraded, or are being degraded or have potential to be degraded. The term degraded when used in the above manner covers a variety of conditions such as unacceptable levels of chemicals, unacceptable responses to bioassay tests, unacceptable levels of health indicator bacterial populations and pathogenic microorganisms, presence of algal blooms, or presence of aesthetically deteriorated waters due to floating debris.

In our laboratories we have undertaken a series of studies to evaluate the suitability of a variety of microbiological. biochemical and bioassay tests to become part of a "battery of test procedures" to identify degrading water bodies. The final

"battery of tests" selected would be used nationally to prioritize specific water bodies and sediments for immediate remedial action or future investigations. The "battery of tests" approach will make it possible for chemists to decide which water and sediment sample will receive detailed chemical analyses and which samples can be omitted from the analysis routine. Also the "battery of tests" approach will make it possible to establish "hot spots", areas of immediate concern, which were not previously suspected due to inappropriate/inadequate or one-dimensional testing procedures. In the final selection of the "battery of tests" those tests which can be performed on samples stored (frozen or refrigerated) for a minimum period of 30–48 hours, would be given priority for selection.

The tests which are being evaluated for our battery of tests are: *Water Column Tests*: coliphage (Dutka *et al.*, 1987), fecal coliform membrane filter test, using mFC agar, fecal streptococci membrane filter test using KF agar, the fecal sterols, coprostanol and cholesterol (Murtaugh and Bunch, 1967; Dutka *et al.*, 1973), Microtox (Beckman, 1982), *Spirillum volutans* (Dutka, 1986), ATP-TOX System (Xu and Dutka, 1987), Algal-ATP (Dutka, 1986), SOS Chromotest (Fish *et al.*, 1985), *Daphnia magna* (APHA, 1985) and *Ceriodaphnia reticulata* (Mount and Norberg, 1984).

Sediment and Sediment Extract Tests: fecal coliform, most probable number technique using A-1 Broth; *Clostridium perfringens*, most probable number technique with confirmation in litmus milk (Dutka *et al.*, 1986), Microtox, ATP-TOX System, *Spirillum volutans*, Algal-ATP, SOS Chromotest, *Daphnia magna* and *Ceriodaphnia reticulata*.

The *fecal coliform* and *fecal streptococci* bacterial indicator tests used in these studies are the traditional tests used in North American water quality studies.

Coliphage: Coliphage are bacterial viruses (bacteriophage) which infect and replicate in lactose fermenting, Enterobacteriacae (coliforms and fecal coliforms). Since coliphage replicate only in coliform and fecal coliform organisms, the finding of coliphage in water samples also indicates the possible presence of these indicators and other pathogenic organisms including viruses. The coliphage procedure used in these studies is similar to that found in section 919C of the 16th edition APHA Standard Methods (1985). This procedure can theoretically detect one coliphage (1 coliphage in 100 mL of water sample) where water turbidity is not in excess of 25 NTU.

Clostridium perfringens: C. perfringens is probably the most widespread pathogenic anaerobic organism on earth and its distribution is considered to be ubiquitous (Bonde, 1963). The natural habitat of this organism and the only place where it can form spores is in the colon of warm-blooded animals (Bonde, 1963). Its occurrence in nature is consequently dependent on the presence of fecal pollution. In our tests we examine for the spores of *C. perfringens* which can survive for years in sediments.

In our assessment of the various microbiological procedures as future cadidates for the "battery of tests" approach, we have found that the coliphage test and *C. perfringens* test can be done on samples, refrigerated for at least 36 hours without count variations. Thus these two tests are high on our priority list as bacterial candidates for the final "battery of tests".

Many studies (Murtaugh and Bunch, 1967; Dutka *et al.*, 1973) have shown that certain fecal organic compounds, such as coprostanol and cholesterol have the potential of being used as indicators of recent fecal pollution. Coprostanol (5^{β}-

cholestan-3-ol) is one of the major fecal sterols excreted by many higher animals and chickens. Cholestrol a precursor of coprostanol in the gut of mammals and chickens, is converted to coprostanol by chemical reduction and/or by anaerobic gram negative flora. As cholesterol is also found in eggs, milk, lard and wool grease, it is not as specific an indicator of fecal pollution as coprostanol.

Thus, the finding of coprostanol in water or sediments indicates contamination by excreta from either domestic wastes or runoff from pastures or barnyards. On the other hand the finding of cholesterol in water and sediments would be highly suggestive of fecal contamination. Water and sediments for these tests can be preserved and tested weeks after collection.

Toxicant Screening

The following described toxicant screening tests can be performed on water samples and sediment extracts that have been preserved by refrigeration or frozen. Frozen samples can be examined at leisure 2 or 3 months after collection.

Spirillum volutans. The organism *S. volutans* is a large aquatic bacterium which is readily visible under low magnification. It has a fascicle of flagella at each end which, under normal conditions, form oriented revolving cones allowing the bacterium to move forward and reverse directions at will. During the reversing process the polar fascicles reorient simultaneously. To perform the test, *S. volutans* is added to a volume of the sample and the mobility of the organisms is observed with a microscope. If the sample is toxic but contains non-lethal levels of toxicants, *S. volutans* loses coordination, as both fascicles try to assume the head or tail orientation, thus preventing normal bacterial motion.

Microtox. Beckman Instruments, Inc. have devised a test for acute levels of toxicants in water or sediment extracts, in which specialized strains of luminescent bacteria (*Photobacterium phosphoreum*) are used as the bioassay organism. This test is functional because the metabolism of the luminescent bacteria is influenced by low levels of toxicants and, occasionally stimulants. Any alteration of metabolism affects the intensity of the organism's light output. By sensing these changes in light output, the presence and relative concentration of toxicants can be obtained by establishing the EC_{50} levels from graphed data: EC_{50} being that concentration of toxicant causing a 50% reduction in light from the baseline level.

Genotoxicity Test. The test consists of colorimetric assays of microbial enzymatic activities after incubating the bacterial tester strain (*E. coli* K12-PQ37) in the presence of various concentrations of water or sediment extract. An exponential growth phase culture of the *E. coli* is introduced into the cells of a microtitration plate containing samples and controls. After a two-hour incubation at 37°C, a chromogenic substrate is introduced, which lyses the bacteria and a colour develops after a short incubation. The intensity of the colour reaction can be analyzed visually. For more precise analysis, the SOS Chromotest microplate can be read in a microtitration plate reader. The more intense the colour (blue) the greater the concentration of genotoxicant.

ATP-TOX System. The concentration of ATP per bacterial cell remains relatively constant and stable throughout all phases of growth (D'Eustachio and Johnson, 1968). Thus bacterial densities can be easily estimated by measuring the ATP content of the test system. When rapidly growing bacterial cells are exposed to toxicants, growth inhibition usually occurs. After several life cycles the toxic effect

can be estimated by comparing sample cell growth to the control via ATP content. However, some toxicants not only inhibit bacterial growth but also affect the luciferase activity during ATP determinations. Therefore, the observed light output reduction of the test system is the net result of the inhibition of both bacterial growth and luciferase (called "total inhibition of the ATP-TOX System"). Luciferase activity inhibition can be determined by adding a standard ATP solution, as enzyme substrate, to the sample and to a distilled water control and measuring the light emission of the enzyme. In our studies, we use *E. coli* K-12 PQ37 strain, although any bacterium or mixture of bacteria can be used in this technique.

Algal-ATP. The algal-ATP toxicant screening test is based on the inhibition of ATP production in cultures of the green algae *Selenastrum capricorutum* (Blaise *et al.*, 1984). The ATP content of the stressed *Selenastrum* is measured by the procedure described in the Turner Luminescence Review 1983. The results are reported as a percentage of Relative Light Output (RLO) of the non-stressed controls which is 100%.

Daphnia magna. The *Daphnia magna* used in our tests is the largest of the *Daphnia*, often reaching 5 mm in size. The neonates (first-instar young) are 0.8 and 1.0 mm long and can be observed by eye. This stage is the one most commonly used for tolerance studies. Tests are performed on neonate *Daphnia* that have been released from the mothers brood chamber during the previous 24 hours. In the test, 10 neonates are used for each dilution of sample to be tested (APHA, 1985). The neonate *Daphnia* are observed at 1 hr, 4 hr, 24 hr and 48 hr, and the number of dead animals are recorded. A 24 hr or 48 hr EC_{50} value is then derived from the pattern of deaths observed. *Daphnia* are less tolerant of toxic substances than are fish (Kemp *et al.*, 1976).

Ceriodaphnia reticulata chronic toxicity Test. The Cladoceran, *Ceriodaphnia reticulata* is used to evaluate the chronic toxicity of a sample. In this test six beakers of approximately 30 mL volume are used for each sample dilution and control with one animal per beaker. Tests are performed with young animals that are as similar in age as possible (8 hrs maximum). On the 3rd, 5th and 7th day of the test, the young are counted and discarded. During the test period the animals are fed daily. At the end of the test the number of young per original adult and the number of broods per adult are established against that obtained in the control sample. An average of 2.5 broods per adult in the controls has been used as the end point in some testing procedures (Mount and Norberg, 1984).

In order to compare water and sediment samples with each other and others collected nationally a point value scheme was devised, based on the results of each test procedure in order to allow for a ranking of samples from least concern to greatest concern. The point allocation scheme is biased and not scientifically defensible, but it reflects the authors' experience with various concentration levels of toxicant activity and health related bacteria in Canadian waters and sediments. The present rating scheme is a viable entity which will change with increased data accumulations and when greater experience is gained.

Samples with the most points are deemed to contain the greatest potential hazard to man and organisms found in the aquatic ecosystem. High toxicant levels may have reduced microbial levels/activity in some sediment samples; however, cause and effect relationships were not investigated. This is an area of future research.

Summary

From our stream and river studies, we have learned that a single input of fecal material can pollute a water course for at least 20 km and 162 days. However, the movement of bacteria and particle bound bacteria in a water course appears to be so variable that at present this movement is difficult to predict, especially in slow moving water bodies. We believe more research is necessary on the movement of different sized and density particles with ab/adsorbed bacteria and chemicals, in order to estimate sedimentation rates and distribution patterns of bacteria and toxic chemicals in streams and rivers.

As our research studies have shown that sediment composition plays an important role in microbial survival and multiplication which in turn play an important role in the biodegradation and biotransformation processes, we believe more studies are required on the interrelationships between sediments (size and density), chemicals, bacteria and other stressing factors such as temperature, dissolved oxygen and sunlight.

The "battery of tests" approach will, when an appropriate "battery of tests" is established, be a major factor in helping the understanding of pollutant/stream/river interactions. Also, the "battery of tests" approach will enable managers to make decisions on priority concerns and observe the impact of their decisions by the new data produced by this battery of tests.

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Microbiological Quality of Selected Streams in Southwestern Ontario

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In southwestern Ontario, the microbiological quality of most rivers and streams has been found in many cases to be unacceptable based on recreational water quality objectives, livestock watering guidelines and potable water standards. The microbiological quality of rivers and streams in the region tends to decrease from the north (Georgian Bay), to the south (Lake Erie) as is shown in Table 1. Fecal coliform levels are significantly higher in the Sydenham and Thames Rivers to the south than in the Sauble and Saugeen Rivers to the north. Although these fecal indicator bacteria have been found to originate in a few urban inputs (stormwater, combined sewerage and sewage effluents), the major input of fecal bacteria to these rivers is non-point sources associated with agriculture.

The actual fecal waste contaminating streams is comprised of bacteria, fungi, viruses, and parasites (National Research Council, 1983). It has been demonstrated that bacteria such as salmonella, campylobacter, clostridia and enterotoxigenic *E. coli* are associated with the levels of pollution indicator bacteria being recovered from these water courses (Olivieri, 1982).

In 1983, the microbiological quality of beaches was reported to be ranging from poor to completely unacceptable across the province of Ontario. Medical Officers of Health, during the summer months, were challenged frequently as to when bathing beaches would again be suitable for recreational activity. Revenue losses were reported in many resort communities to be in order of millions of dollars (Burger, 1985)

The Ontario Ministry of the Environment was requested by County Health Units, whose mandate was to manage bathing beaches, to assist in defining the sources of fecal associated bacteria polluting the beach water and to implement abatement measures as soon as possible.

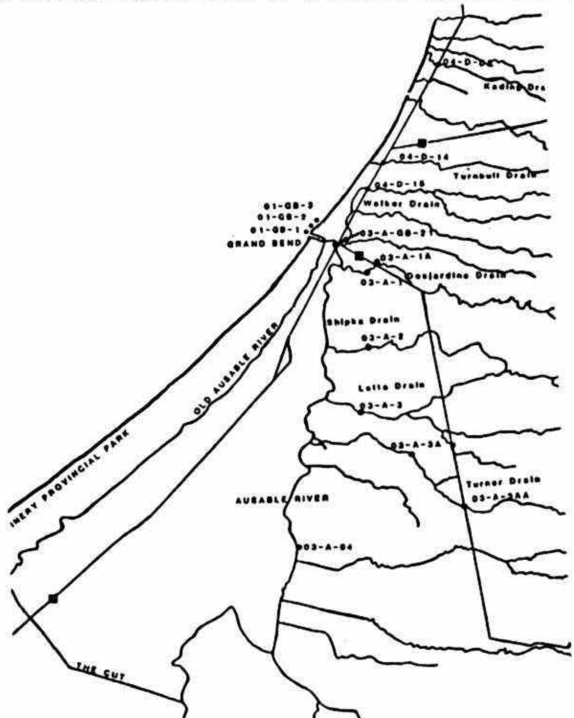
An intensive beach pollution study was initiated in the early summer of 1984 in southwestern Ontario. The focus of the 1984 study was on three beaches. Ipperwash Provincial Park, Grand Bend and Goderich were selected for the study. Each beach was carefully chosen based on different topographies and the number of people using the swimming sites. The actual study was comprised of 14 components which addressed the fecal bacterial contributions from storm water and sewage treatment facilities to contributions from pleasure craft in marinas and from the bathers themselves. Results as reported in MOE, (1984) indicated that, although a few storm sewers were polluted with sanitary sewage, it was evident that the major source of fecal associated bacteria affecting the beaches was non-point source pollution of agricultural origin.

TABLE 1: Geometric Means of Levels of Fecal Coliform Bacteria inS Selected Rivers in Southwestern Ontario

River	Geometric Means of Fecal Coliforms (per 100ml)
Sauble River	40
Saugeen River	121
Maitland River	158
Ausable River	142
Sydenham River	267
Thames River	356

Open drains and streams containing surface run-off and subsurface or field tile drainage from agricultural land were found to be polluted with levels of fecal indicator bacteria ranging from 10^3 to 10^7 organisms per 100 mL. Similar results have been reported by Culley and Phillips, (1982), and Doran *et al.*, (1981).

FIGURE 1:: STATION LOCATIONS OF THE LAKE HURON BEACH STUDY



Some of the open drains discharge directly to Lake Huron while others discharge to rivers such as the Ausable (Figure 1). Because of wind direction and currents, river water containing high levels of suspended particulates and fecal associated bacteria, upon discharging to Lake Huron, often moves onto the beaches. The microbiological water quality of the beach water based on the fecal coliform recreational water guidelines of 100 organisms per 100 mL, rapidly decreases making the water unacceptable for swimming, (Figure 2).

During investigations of the sources of fecal associated bacteria and particulates in streams in the vicinity of intensive dairy, beef and swine farming, field tile were found to contain significant levels of pollution indicator bacteria and pathogenic microorganisms (Balint, 1985, Thornley, 1984). *Salmonella species* and *Pseudomonas aeruginosa* were frequently isolated from drainage at levels that were similar to raw sewage. Closer investigation revealed that field tile, which were designed to rid cropland of excess water during wet periods, were actually being used to dispose of milkhouse wastes, ponded manure laden water in barnyards, excess water around manure piles and septic tank overflow discharges. Detailed field tile investigation confirmed the connection of field tile to drainage carrying both animal and human feces (Glasman and Hawkins, 1985).

Further investigations of farmland in various watersheds also demonstrated that direct cattle access of streams and drains, for livestock watering purposes, resulted in excessive levels of fecal associated bacteria entering the water course (Demal, 1983).

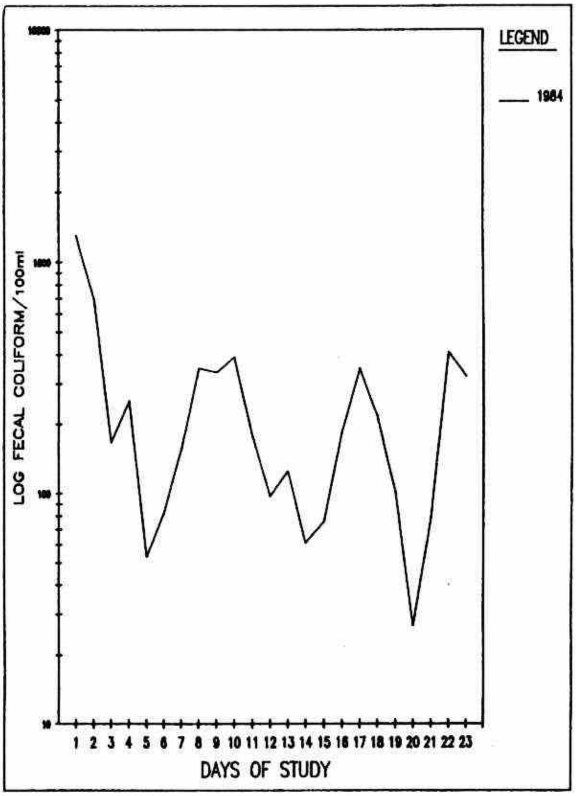
In summarizing the conclusions of stream quality and recreational water quality studies it is evident that elevated levels of fecal associated bacteria and suspended particulates are common pollutants in streams and rivers and recreational beach waters in southwestern Ontario. In beach studies conducted by Palmateer and Huber, (1985), suspended particulates, to which bacteria and viruses become attached, appear to become re-suspended from bottom sediments by rigorous wave action which results in excessive levels of fecal associated bacteria in the water column. MOE, (1984) also showed evidence of the effect of bacterial contaminated sediments being re-suspended during rough lake conditions. Fecal coliform levels in the water column increased sharply while under calm lake conditions bacterial levels in the water column would decrease to concentrations safe for swimming.

The temporal aspect of bacterial pollution events of streams was found to have a profound effect on the microbiological quality of streams and subsequently on beach water quality. It has been demonstrated by Matson *et al*., (1987), and Hendricks, (1971), that once bacteria become sorbed to particulates the period of survival often increases from days to months.

Various methods have been employed to study bacterial survival in water and sediment. Recently, the use of polycarbonate or plexiglass chambers with porous membrane sidewalls such as designed by McFeters and Stuart, (1981), has provided evidence of the lengthy survival of bacteria and algae in streams.

As part of the Lake Huron beach studies, sterile sediments inoculated with *Escherichia coli* within chambers demonstrated a survival period of greater than one month in Lake Huron. Survival in the water column ranged from three to five days only (Figure 3). In comparison *E. coli* survival in the nutrient rich waters of the Ausable River was approximately three weeks (Figure 4). Concentrations of nitrogen, phosphorous and carbon, used by the bacteria for maintenance, were be-

FIGURE 2: LEVELS OF FECAL COLIFORM BACTERIA IN THE BEACH WATER OF GRAND BEND DURING THE SUMMER OF 1984.



tween 10 and 100 times higher in the Ausable River than in Lake Huron. Water temperatures were similar.

A study of bacterial survival in sterile and non-sterile sediments was conducted by Haymen and Merkley, (1986), using the McFeter chamber. Results illustrated in Figure 5 demonstrate that *E. coli* is able to survive for several months in the sedi-

ment of a river impoundment. The non-sterile sediment data was unique whereby an antibiotic resistent *E. coli* was capable of competing for nutrients with the indigenous bacteria within the die-off chamber. The extended survival in the sterile sediment chamber was expected because of the lack of competition for nutrients and the absence of protozoan predators. Use of a genetically marked bacterium in natural sediment appears to provide more representative data concerning bacterial survival. Dutka and Kwan, (1980), also reported a lengthy survival period of *E. coli*,

FIGURE 3: SURVIVAL PERIODS FOR *ESCHERICHIA COLI* IN LAKE HURON WATER AND SEDIMENT

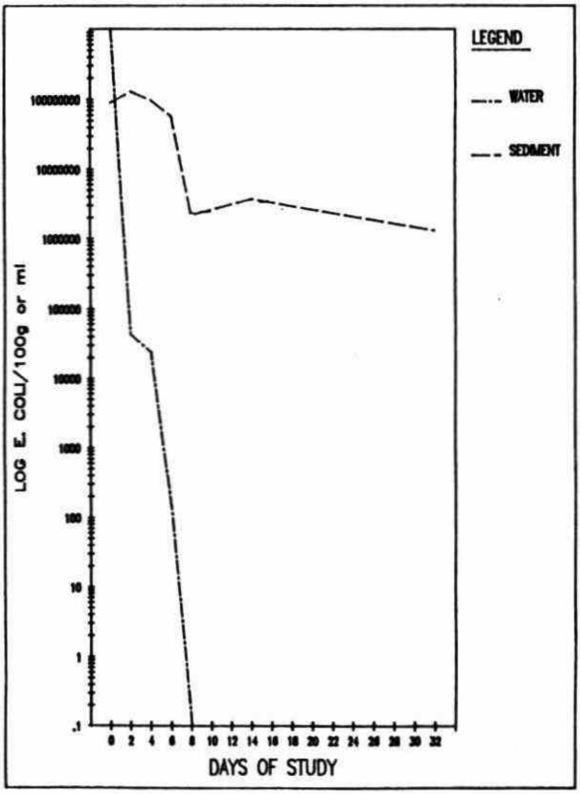
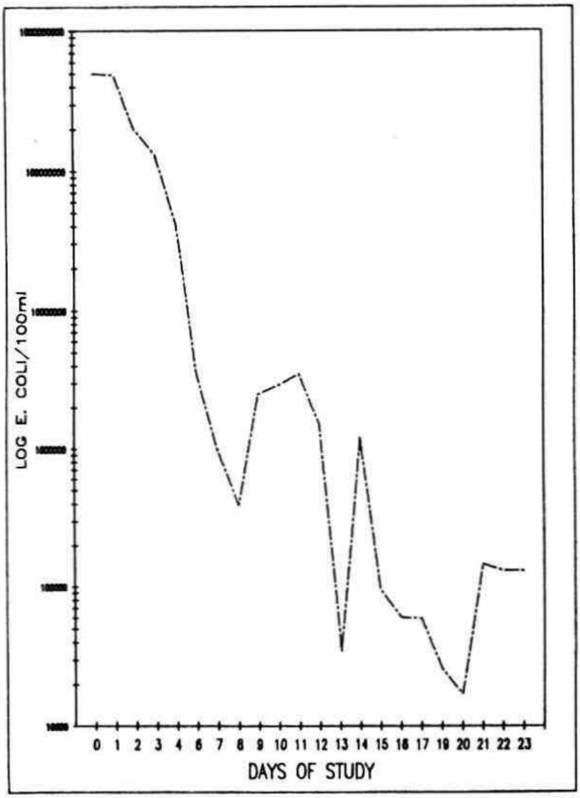


FIGURE 4: LEVELS OF *E. COLI* IN THE AUSABLE RIVER DURING A 3-WEEK PERIOD IN A CHAMBER

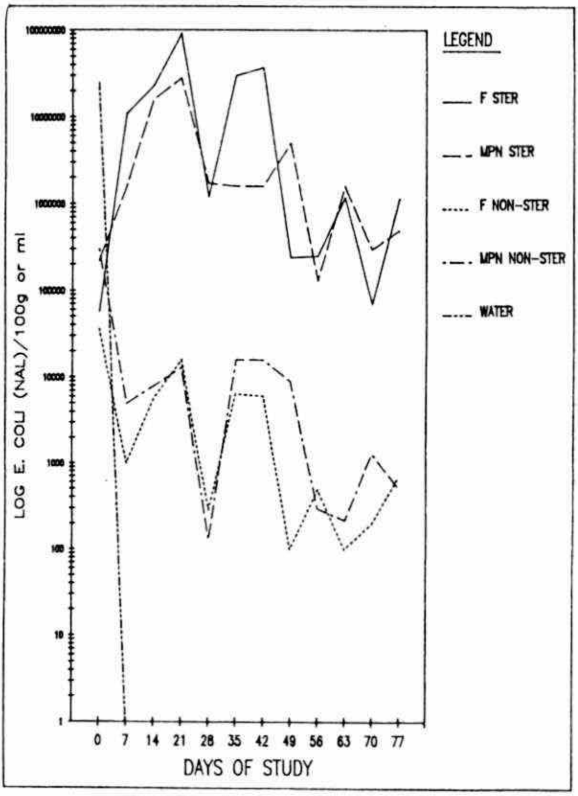


S. fecalis and *Salmonella thompson* in Lake Ontario and Hamilton Bay. In the same study, *Serratia marcescens* was used as a tracer in a small stream. The bacterium was recovered for 22 days and was traced for a total distance of 20 km, indicating the distance bacteria can travel when released in a stream.

During rainfall periods, soil moisture content increases depending on the moisture holding capacity of the soil type. Bacteria found in manure applied to soil, but not incorporated, tends to be washed readily from stream banks provided that sufficient rainfall occurs to result in runoff (Khaleel *et. al.*, 1980). The amount of vegetation on the stream bank also effects the moisture holding capacity of the soil and

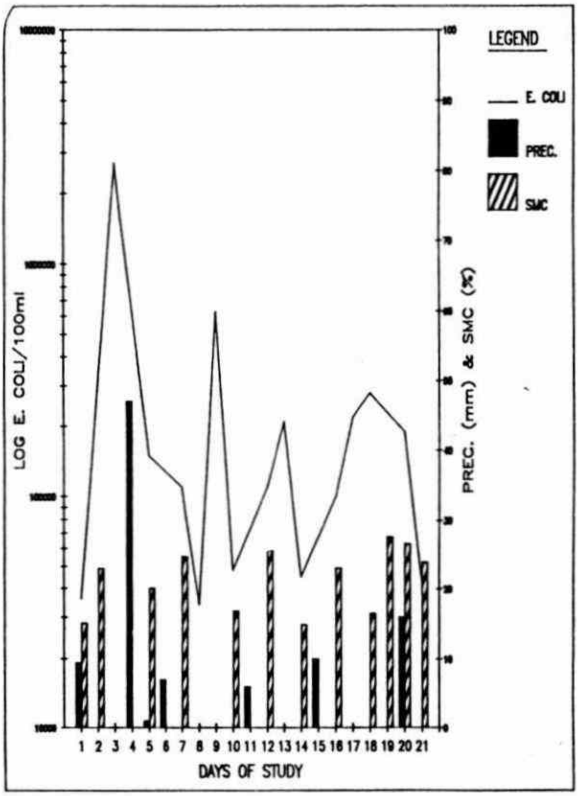
FIGURE 5: LEVELS OF *E. COLI* (ANTIBIOTIC RESISTANT) IN CHAMBERS CONTAINING EITHER WATER, STERILE SEDIMENT OR NON-STERILE SEDIMENT.

Most probable number (MPN) and Membrane filtration (f) were used to enumerate the bacterial levels.



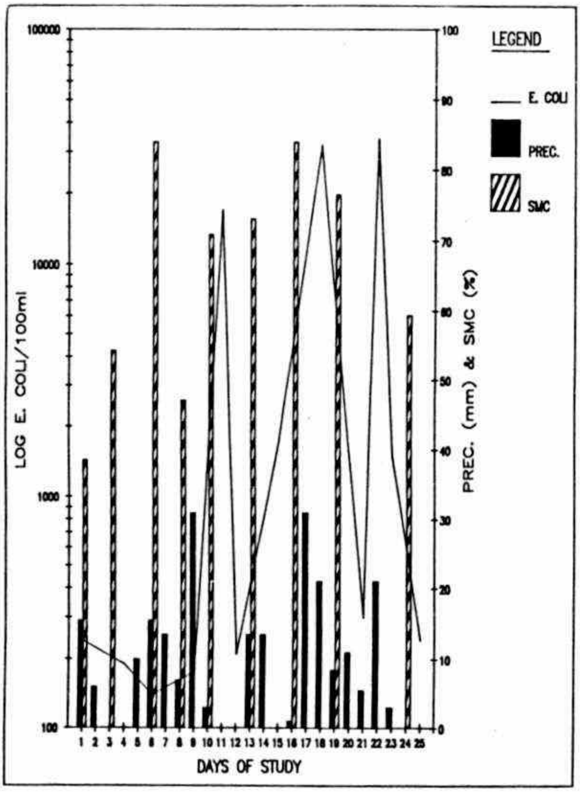
the runoff which may occur during a rain event. Recent studies in the Ausable River watershed have demonstrated that, if the soil moisture is sufficiently high, runoff from even a minimal rainfall event will result in elevated levels of *E. coli* in the stream,

FIGURE 6: FLUCTUATIONS IN THE LEVELS OF *E. COLI* IN RESPONSE TO RAINFALL AND SOIL MOISTURE (SANDY SOIL)



(Figures 6 and 7). The difference between the moisture holding capacity of soils and the amount of rain which would cause bacterial increases in the stream is evident when sandy and loam soils are compared. Both soil and manure, when washed into streams, results in high levels of fecal indicator and pathogenic bacteria entering the stream. Studies by Kundle, (1970), and Stephenson and Street, (1978) have reported similar results. Springer, *et. al.*, (1983) demonstrated that thirty day old cat-

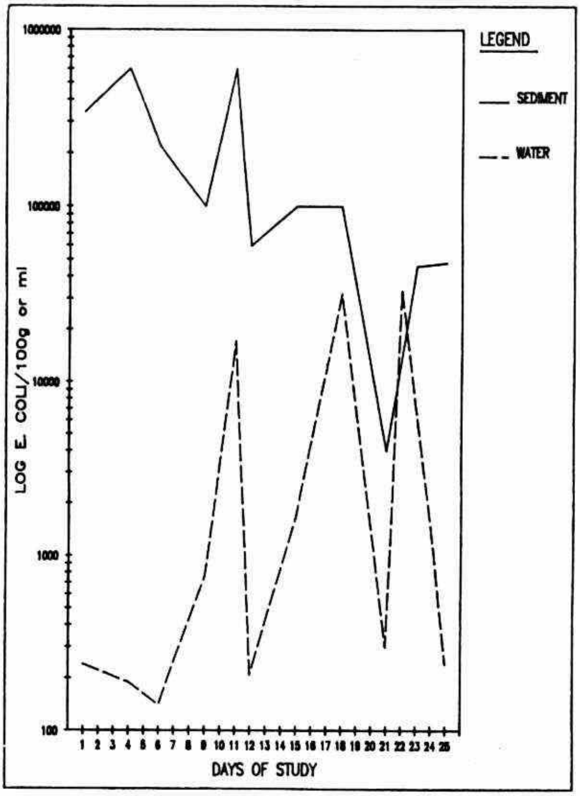
FIGURE 7: FLUCTUATIONS IN *E. COLI* LEVELS IN RESPONSE TO RAINFALL AND SOIL MOISTURE (LOAMY SOIL)



tle feces when rained upon, released fecal coliform bacteria at a rate of 40,000/100 mL of runoff, thereby contaminating the receiving stream water and sediment.

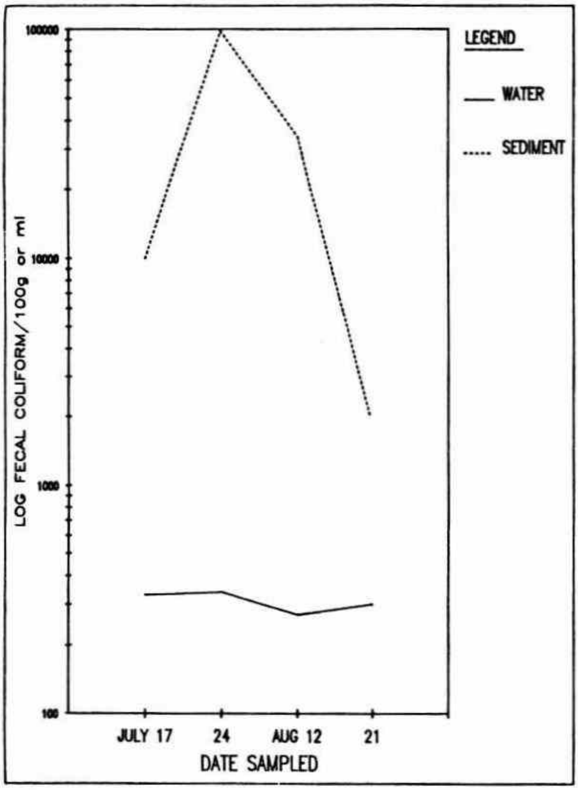
As the concentration of fecal coliform and microbial pathogens in the stream increases, the potential health risk to both humans and animals contacting the water also immediately increases. A major concern regarding the presence of enteric bacteria, of livestock origin possessing multiple antibiotic resistance has been reported

FIGURE 8: LEVELS OF *E. COLI* IN WATER AND SEDIMENT OF THE DESJARDINE DRAIN WHICH DISCHARGES TO THE AUISABLE RIVER



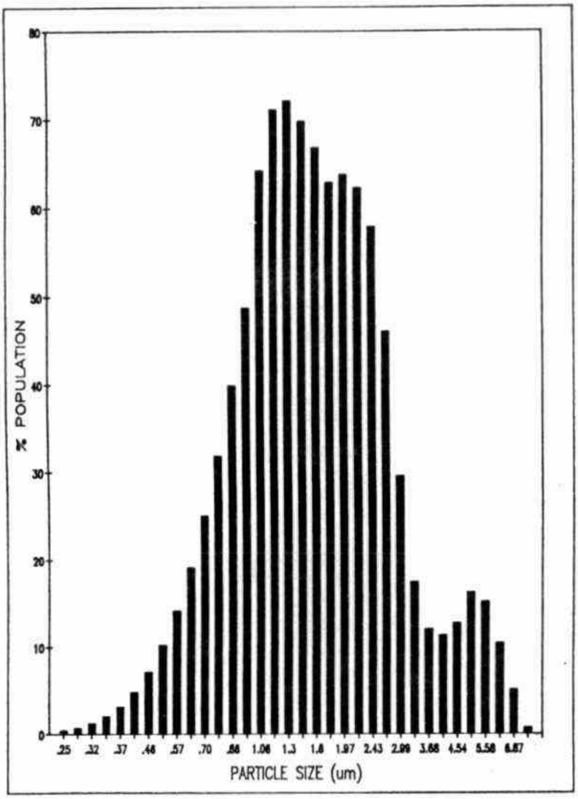
by Nine *et. al.*,(1981). Palmateer and Huber, (1985), found considerable multiple antibiotic resistance with E. coli recovered from streams receiving runoff from farms. The antibiograms demonstrated resistance to antibiotics primarily used by veterinarians. As a result of the ability of E. coli to transfer the resistence to other pathogenic bacteria, added health risk occurs to both humans and livestock.

FIGURE 9: LEVELS OF *E. COLI* IN WATER AND SEDIMENT OF THE AUSABLE RIVER NEAR GRAND BEND



Sediment sorption by bacteria occurs concomitantly during actual runoff resulting in fecal bacteria becoming rapidly sorbed to soil particulates. In addition, sorptive particulates in the water column may originate from the resuspension of the stream bottom sediments. The result is that the stream sediments become a reservoir for *E. coli* (Stephenson and Rychert, 1982), (Figure 8 and 9).

FIGURE 10: ANALYSIS OF SUSPENDED PARTICULATES IN A STREAM SHOWING THE PARTICULATE SIZE DISTRIBUTION



Since microorganisms in stream water are generally in a nutrient deficient environment, adhesion to nutrient rich particulates is advantageous for survival. Marshall, (1980), has described two basic mechanisms of sorption to particulates. Microorganisms attach to particulates of like charge, where van der Waal forces exceed the electrical double-layer repulsive forces. Typically, a microorganism is held at a small but finite distance from the surface of the particulate. When sorbed in this manner, the potential for deposition by shearing forces is significant as the microorganism is not physically attached to the particulate surface. This type of sorption is considered reversible.

In contrast, permanent sorption involves the anchoring of the microorganism to a particulate surface by polymer bridging. Substantial shearing forces cannot overcome this physical adhesion mechanism.

It is this latter type of sorption that likely provides for lengthy bacterial survival periods. In addition, the type of sorbant can affect bacterial survival. Clays have been demonstrated to enhance microorganism survival by protecting the organism from ultraviolet and x-ray irradiation, desiccation, antibiotics, and predator-prey interactions, (Marshall, 1980). The efficiency of parasites and predators is significantly reduced by sorption of bacteria and viruses to particulates.

To evaluate the contribution of high levels of microorganisms in sediment to the stream water quality it was deemed necessary to consider the specific sorptive mechanism involved. Litchfield, (1979), reported in a comprehensive study on bacterial desorption from particulates, that the type of sorbent dictates the type of desorption procedure. Therefore, depending on the method used, the accuracy of the sediment bacterial data may be in question. Furthermore, the type of enumerative procedure employed to determine the microbial populations in sediments also affects the accuracy of the data. Seyfried *et. al.*, (1979), found that the most probable number determinations underestimated *Pseudomonas aeruginosa* concentrations in sediments between 39 and 98 percent using 1 to 10 dilutions, as compared to plate counts. If higher dilutions were required, the percent underestimation increased further. Plate counts and various fluorescence microscopy techniques have been shown to be most reliable (Marshall, 1980).

Using the preceding methodology considerations, microbial sediment studies were conducted by MOE, in 1984 and 1985. Beach sediments of Lake Huron, as well as rivers and drains discharging into Lake Huron, were sampled. Correlations between bacterial concentrations, as measured in the overlying water, with turbidity and suspended solids measurements proved unsatisfactory. It was apparent that neither parameter was measuring the suspended particulates to which fecal associated bacteria were attached. These techniques appeared to be too course in estimating the actual bacterial concentrations associated with sediments. In contrast, Seyfried and Harris, (1986), were able to show an association between increased *E. coli* levels and increased suspended particulates in the Humber River and Black Creek. A gravimetric method was employed in their study. It is evident that the actual suspended particulate size and type in these streams, which acts as the sorbent for fecal associated bacteria, remains relatively unknown.

To date, further investigations are continuing to define the precise size and type of stream sediments which are acting as sorbents for fecal associated bacteria. Size analyses coupled with organic and inorganic determinations are being conducted. In our laboratory, using the procedures of particle sizing and counting as reported by Kranck and Milligan, (1979), and Tsernoglou and Anthony, (1971), the size of suspended particulates in streams are being examined. Initial data is exhibited in Figure 10. A variety of streams in the region are going to be characterized, as shown here, on a monthly basis. Subsequently, differential filtration techniques will be used to recover the various size ranges of stream particulates. *Escherichia coli* and fecal *Streptococcus* concentrations sorbed to the specific sizes will be determined using immunofluorescence microscopy.

It is anticipated that this direct approach will provide more accurate information regarding the type of suspended particulates that transport high numbers of fecal associated bacteria many kilometers downstream.

The implications of microorganisms of animal and human origin entering streams, on a year round basis, at many points along the stream banks, in conjunction with

the survival period once in the stream and the potential distances that sediment associated bacteria may travel are such that, unless the sources of fecal wastes are reduced or eliminated, untreated water as a resource in southwestern Ontario for drinking of for recreational purposes will unlikely exist in the near future.

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Natural River Ecosystems: The Ultimate Integrator

J.G. Imhof, N.K. Kaushik, J.B. Bowlby, A.M. Gordon, R. Hall

"In rivers the water you touch is the last of what has passed and the first of that which comes. So with time present."

Leonardo da Vinci 1451-1519
Codex Trivulziano fol 34 r., Milan

1.0 Introduction:

Consider the parallels between rivers and time. Both describe a continuum of actions, events and change that often shape and change the course of our life. Only recently are scientists and lay public alike realizing the implicit relationship between the physical, chemical and biological processes of a river and its catchment. In the truest sense of the word, rivers become the integrator of these processes, changing, adjusting and evolving over time as landuse in the catchment changes.

This paper will provide an overview of how natural rivers and their unaltered catchments are implicitly linked and provide the framework for comparing the effects of deforestation, agriculture and urbanization on rivers and their catchments. This is not intended to be an exhaustive review but primarily intended to provide a "point in time" view of natural aquatic river ecosystems.

The first part of this paper reviews and examines the general inter-relationships between biotic and abiotic features of the catchment, its climate and geology, and the river channel and its morphology. The second component examines several important variables which control and mediate the type, diversity of locations of biotic assembelages in rivers. The final section of the paper examines how these features affect the dynamics of fish communities in natural river systems.

2.0 General Interrelationships:

Rivers differ quite dramatically from lakes. Lakes have relatively well defined boundaries within which the cycling of organic matter predominates. Rivers on the other hand show a strong directionality and interact implicitly with their catchment (Hynes 1975). Cycling of nutrients and organic matter occurs slowly in lakes and is often disjunct as many nutrients are often lost to the substrate. However, cycling of nutrients and organic matter occurs slowly in lakes and is often disjunct as many nutrients are often lost to the substrate. However, cycling in rivers can occur more quickly because the shallow, turbulent nature of rivers keeps nutrients and organic matter constantly available to the aquatic biota. This, in turn, may lead to higher productivity in rivers versus lakes. The physical processes in lakes, especially large lakes, are more stable than in rivers and react more slowly to physical alteration. Major differences between rivers and lakes are summarized in 6 dichotomies presented in Table 1.

TABLE 1: Dichotomies between Rivers and Lakes

Spatial - Temporal Orientation
Horizontal vs Verical Stratification
Exogenous vs Endogenous Environmental Sources
Allochtonous vs Autochthonous Sources of Energy and Nutrients
Relative levels of Abiotic and Biotic Effects
Distribution of Heterotrophic and Autotrophic Production

From Ryder and Psesndorfer (1988)

In order to differentiate between sections of rivers, a number of ordering and classification systems have been developed. The system developed by Horton (1945) and modified by Strahler (1957) numbers the tributaries of a river beginning with headwater tributaries (Order 1) and increasing the order number as lower order tributaries join the mainstream (Figure 1). Under Strahler's classification, Order 1 streams are classified as unbranched tributaries. Order 2 streams are formed by the confluence of two Order 1 streams: Order 3 by the confluence of two Order 2, etc. Various researchers have shown relationships between the numbers and

FIGURE 1: RIVER CLASSIFICATION BY A. HORTON 1945; B. STRAHLER 1957

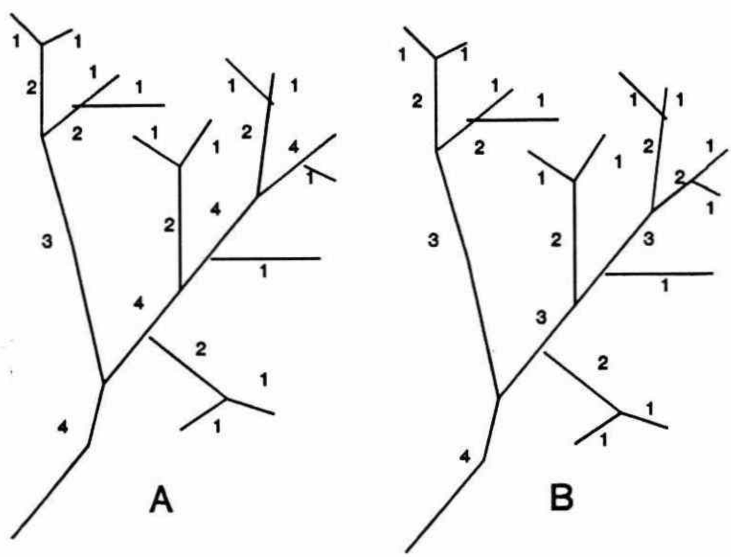
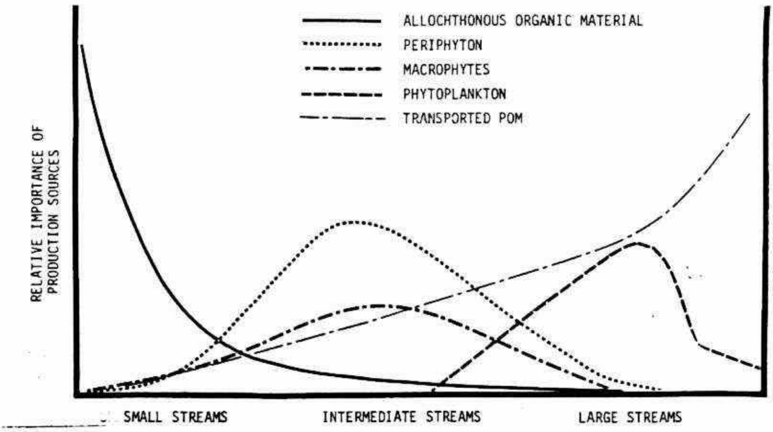


FIGURE 2: RELATIONSHIPS OF SOURCES OF PRIMARY PRODUCTION AND TRANSPORTED PARTICULATE ORGANIC MATTER (POM) TO STREAM SIZE.
(Modified from Benfield 1981)



lengths of streams of each order. Generally they indicate that the number of streams of different order in a watershed increases with decreasing order in a regular manner (Leopold et al 1964; Welcome 1986).

Another system proposed by Illies and Botosaneanu (1963) separates rivers by their slope and substrate character into high gradient river sections (rhithron) and low gradient sections (potomon). The rhithron is typically classified in temperate regions as the section extending from the source of the river to the point where mean monthly temperatures rise to 20°C. Oxygen concentrations are always high, flow is swift and turbulent and the stream substrate is coarse, composed of boulders, rubble and gravel. The potomon begins where monthly mean temperatures rise to 20°C, oxygen deficiencies may occur, flows are gentle and the stream substrate is composed of sand and mud (Hynes 1970). Some researchers have limited the classification of rhithron and potomon to primarily physical forms of channel slope, velocity and substrate (Welcomme 1986). Both systems are still used today.

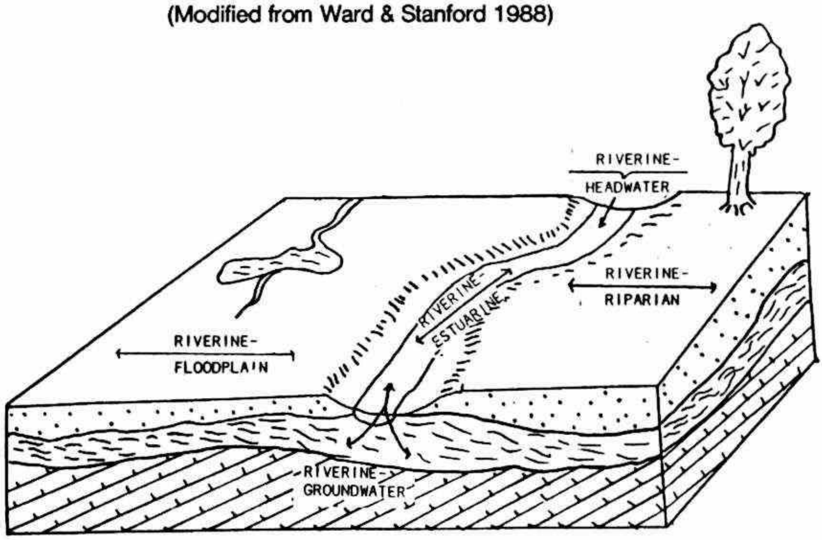
Several new approaches to defining the form and function of rivers have been suggested in the last several years. The River Continuum Concept (R.C.C.) (Vannote et al. 1980) and its modifications, (Minshall et al. 1985; Sedell and Richey 1988; Statzner and Higler 1985; Ward and Stanford 1988) are attempts to define a river as a continuum or disrupted continuum of physical, chemical and biological interaction from headwaters to mouth.

The R.C.C. is based upon the concepts inherent in the energy equilibrium theory of fluvial geomorphologists. Vannote et al. (1980) propose that a river presents a continuous gradient of physical conditions. Accordingly, we should see consistent

length of the river system and a continuum of biotic adjustments. They hypothesize that there is a balance between the distribution of utilized energy inputs over time; the overall principle being minimum energy loss in the system. The balance occurs between efficient use of energy inputs through resource partitioning and the opposing tendency for a uniform rate of energy processing throughout the year. Under their hypothesis, headwaters are the major energy exporters while downstream reaches capitalize on this export inefficiency. The changes in processes as water moves downstream is illustrated in Figure 2.

Modification to the R.C.C. and elaboration of energy pathways have been proposed. Minshall et al (1983) suggest that numerous deviations in the R.C.C. concept occur as a result of variations in the influence of watershed climate and geology, riparian conditions, tributaries, and location specific lithology. Ward and Stanford (1988) stressed the need to consider rivers as interactive pathways along four primary dimensions (Figure 3) and that alteration of any of these pathways can have the effect of "resetting" the continuum of biotic and physical conditions at any one location along the system. They proposed a variation to the R.C.C. and call this new hypothesis the Serial Discontinuity Concept (S.D.C.)

FIGURE 3: INTERACTIVE PATHWAYS OF A RIVER CHANNEL AND THE TERRESTRIAL ENVIRONMENT
(Modified from Ward & Stanford 1988)



3.0 Physical Variables

3.1 Surficial Geology, Climate and Geomorphology

Another system of classification complements the R.C.C. and S.D.C. It attempts to classify and describe catchments by their primary elements and reacting forces. The primary elements are climate and geology, the reacting forces are soil and vegetation and the responding force is the riverine ecosystem (Lotspeich 1980); Lotspeich and Platts 1982; Minshall et al. 1985). The catchment influences the river by collecting precipitation and directing some of this water to the stream through groundwater, interflow and runoff. The soils and vegetation within the catchment influence the rate of inflow to the stream, its temperature and chemistry. The degree of bedrock weathering and the type of soil development in the weathered products influences the capacity of the soil to absorb and water, while climate determines soil texture. This in turn controls the soil/water storage capacity for plant communities. Finally, geological structures have a strong influence on morphology of a catchment and its slope stability and steepness. This influence controls erosion and organic loading. The river reacts to all these biotic and abiotic factors by inegrating the components into a stable dynamic system.

In lower order rivers (Order 1–4) riparian vegetative systems can over-ride certain effects of climate and geology (Minshall et al. 1985). Even in larger rivers the lateral components of river flow are controlled in part by riparian vegetation which may modify the channel morphology at specific locations through erosion control and through the input of large amounts of organic matter (i.e. logs) (Conners and Naiman 1984; Ward and Stanford 1988). Bank erosion control encourages the formation of pools and in conjunction with organic matter in the channel enhances the divercity of the stream. Vegetation also can dampen hydrographs through the process of bank storage and flow retardation during floods (Ward and Stanford 1988). This occurs through saturation of streambanks and capture of water in floodplain with concurrent discharge from the banks and floodplain after peak flows. These mechanisms provide critical lateral pathways for biotic energy transfer and beneficial interactions between terrestrial and aquatic biota.

3.2 Hydrology and River Morphology

The S.D.C. and R.C.C. hypotheses have attempted to take into account the relative influence of watershed climate and geology, riparian conditions, tributaries, and local specific lithology and geomorphology on the morphology of river channels and the biota found within and adjacent to them (Minshall et al. 1983; Sedell and Richey 1988; Statzner and Higler 1985; Ward and Stanford 1988). In order to better understand these processes, the action of water within river channels must be understood.

The amount of water available to a stream is dictated by the geology and climate of the catchment. Water enters a stream by 4 primary mechanisms: as direct precipitation, groundwater, interflow, and as overland runoff (Hynes 1970, 1983). In natural unaltered streams, runoff is very uncommon because the terrestrial vegetation acts to capture precipitation and allows percolation into the catchment soils. Once in the soil, it enters the stream both from saturated and unsaturated components of the soil (Hynes 1975, 1983). Therefore most water coming into a stream has had extended contact with the catchment soils. This has strong implications on

the chemical characteristics of the stream. The nature and permeability of the soils also dictates the relative amount of groundwater that will enter the system (Hynes 1970; Lotspeich 1980).

The volume of water as groundwater is much greater in the saturated soils of the valley than in the stream channel (Hynes 1970, 1983). Concurrently, retention times of groundwater within valley soils can exceed 10 years (Hynes 1983). Groundwater flow does not necessarily enter throughout the length of the stream. If the groundwater table is lower than the stream channel, water from the stream will recharge the groundwater table, thereby providing a pathway for water and nutrients back into the substrate (Hynes 1983; Statzner and Higler 1985; Ward and Stanford 1988).

Hynes (1970) cites data that indicate that only approximately 30% of the average annual rainfall (approx. 75 cm) in the U.S.A. eventually enters rivers. There are some losses due to evapotranspiration, deep groundwater and plants. Water that enters the groundwater table also eventually enters the river.

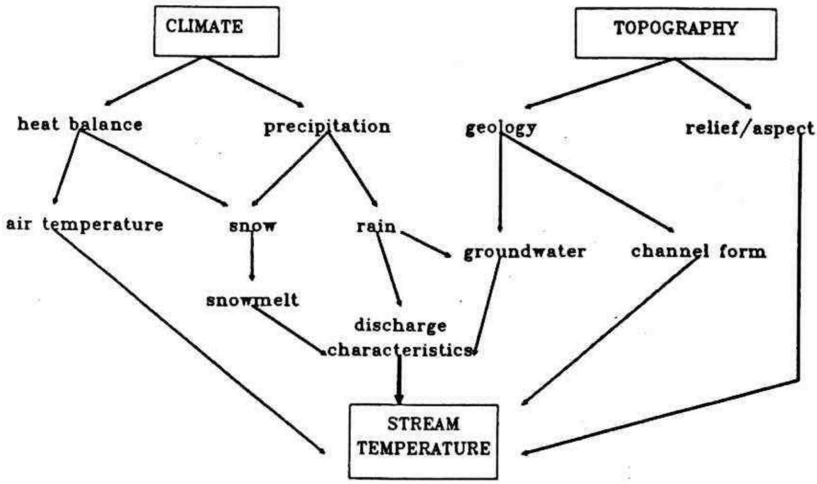
Stream energy is a function of discharge, slope and channel roughness, and is in steady state between river hydraulics and morphology (Heede 1986; Leopold et al 1964). During low flow, stream energy is usually at a level that allows sediment loads entering a stream reach to equal those leaving it. Since sediment load requires energy expenditure from the water flow, a natural stream determines its own ultimate sediment load. If too much load enters a system, beyond the flow's capacity to move it, sediment will be deposited. If too little load is available for the flow, a river will adjust hydraulic features such as width, depth and morphological features to add to the sediment load. In this way a river creates a new steady state between available and expended energy (Heede 1986; Leopold et al 1964; Simons 1976).

In general, rivers reduce energy expenditure by increasing the distance and time it takes to move down a slope (Leopold et al 1984; Leopold and Langbein 1966). This is done by meandering from bank to bank. Where soils are more erodible, a highly sinuous slope to the channel and areas of deposition results. Where slope is steeper and soils coarser, the channel is less sinuous and energy expenditure is often reduced by a vertical staircasing effect (Heede 1986). The meandering action of rivers in natural channels creates pools, runs and riffles and set intervals down the channel; these sequences can be modelled mathematically (Leopold et al 1964).

Riparian vegetation can modify river channels through erosion retardation, creation of vegetated islands and log dams and local scouring effects (Bilby 1984a; Gosse 1963; Hynes 1975; Sedell and Froggatt 1984; Sedell and Richey 1988; Statzner and Higler 1985; Ward and Stanford 1988; Welcomme 1979, 1986). Correlations exist between the amount of bank edge over a length of river (e.g. islands), extent of floodplain inundation (spatial and temporal) and biotic communities, (Gosse 1963; Sedell and Froggatt 1984; Ward and Stanford 1988; Welcomme 1979, 1986). When viewed generally the biotic assemblages within a catchment are controlled by geology and climate but can, to a degree, modify site specific conditions with a resultant enhancement of diversity and stability. The latest revision to R.C.C. (Sedell and Richey 1988) would link classification within the drainage basin context. This approach begins with a description of geology, climate and vegetation, continues to subbasin classification into biogeoclimatic regions and finally zones a river based upon specific biophysical components. This procedure is similar to that proposed by Lotspeich (1980) and Lotspeich and Platts (1982). In this modification

the overall linkages between the physical processes and form, function, and diversity of the biotic community can be partly explained and the changes and adjustments of biotic communities to alterations in physical conditions can be examined and hypotheses developed (e.g. Ward and Stanford 1988; Statzner and Higler 1985).

FIGURE 4: MODEL OF TEMPERATURE INTERACTIONS
(from Smith & Lavin 1975)



4.0 Biophysical Variables

4.1 Temperature

Stream temperature is one of the major in-channel variables. It can have both direct and indirect effects on streams including changes in water viscosity and velocity, nutrient availability, metabolic rate of organisms, species distribution, abundance, diversity and feeding patterns (Hynes 1970; Karr and Schlosser 1978; Kaushid 1981, Smith and Lavis 1975).

In general temperature regime is controlled by the thermal characteristics of the dominant source water (i.e. snowmelt; stormwater; groundwater). Stream size also has an influence (Smith and Lavis 1975). The lower the discharge, the lower the capacity for heat storage and therefore the more responsive the stream becomes to solar radiation and other local environmental factors. Larger rivers have more moderate temperature regimes because of the increase in thermal capacity in the mass of water.

Stream temperatures are controlled by geology, climate and latitude and modified by riparian vegetation (Smith and Lavis 1975). This is based, in part on, the relief,

aspect, channel form and bankside vegetation shielding the stream surface from direct solar radiation (Kaushik 1981; Smith and Lavis 1975). For example, the latter has enormous control on site specific temperature regimes (cf. Barton et al. 1986; Kaushik 1981).

The summer air and ground temperatures in a forest are usually less than in adjacent open fields (Kaushik 1981). Studies in streams flowing through temperate woodlands found water temperature to be about 16°C while those in a deforested watershed were 18-200C (Likens et al 1970). An equilibrium between summer air and water temperatures appears to occur in shaded woodland streams and this can be altered once shade adjacent to a stream is lost (Gray and Edington 1969). Barton et al. (1986) found that once a stream flows out of the protection of forests, water temperatures can heat up at the rate of 2°C per kilometer.

A strong relationship also exists between temperature and aquatic biota (Figure 4). Temperatures may effect life histories, biotic distribution, and feeding and growth patterns (Hynes 1970; Smith and Lavis 1975). Kauskik (1981) mentions that life histories of stream invertebrates as well as the distribution, feeding, and growth of fish are also affected by temperature as are many other biological aspects. Changes in stream temperature regime will usually not have an overt effect on the biota, rather the compensating effects may be quite subtle. Hynes (1969) mentions that certain species of mayflies and stoneflies grow only in cool water, while brook trout, for example, must have water cooler than 14.4°C in order to breed. As well, blackflies emerge only after water temperatures attain 10°C. Therefore the subtle increasing of the temperature regime can negatively affect trout reproduction and prolong the blackfly season.

Groundwater intrusions can moderate the effects of water temperature on the aquatic biota. If the intrusions are small scale, the impact may be the creation of site specific refuges for coldwater dwelling organisms (Bilby 1984b: Cunjak and Power 1986). If the input of groundwater is large, it may reset the community dynamics (Smith and Lavis 1975; Statzner and Higler 1985). Bowlby and Roff (1986) suggest that groundwater may have many other important impacts upon the stream community of which moderating temperatures may only be one.

4.2 Nutrients

Two primary components dictate the potential productivity of an aquatic system: energy and nutrients. Energy is derived from the sun through solar radiation and used to fix carbon in plant tissue through photosynthesis. Nutrients are ions and chemicals that are found naturally in the environment and are used by primary producers to build complex molecules such as proteins, sugars and carbohydrates.

The chemical composition of streamwater is dictated in part by the nature of the rainwater, geology, climate, soils, vegetation and biological processes within and outside the stream (Hynes, 1975; Kaushik 1981). Although the major minerals in the rocks of the catchment dominate the inorganic chemistry of the water, this is somewhat controlled by terrestrial vegetation (Hynes 1975).

Unlike lakes, the nature of flowing water ensures that nutrients are constantly available to the flora and fauna of a stream. The constant absorption, utilization, release and reabsorption of nutrients down a stream is often referred to as nutrient spiralling. (Hynes 1975). The turbulent, unidirectional nature of flowing water ensures that a high rate of utilization of nutrients occurs down the system. The rate of

utilization, (or tightness of the spiralling) can be controlled by slope, substrate, depth, and the biotic community (Minshall et al. 1983). Nutrient input is moderate in naturally forested streams because the successional forests tend to accumulate biologically essential nutrients and therefore streams draining these watersheds usually contain less potassium, nitrogen and possibly phosphorus than streams draining stable, nonsuccessions ecosystems (Vitousek and Reiners 1976; Kaushik 1981).

The R.C.C. hypothesizes that nutrient input, spiralling and utilization in a stream tends towards reduced fluctuations down the system so that community structure and function are maintained at a constant level. Recent work (Sedell and Richey 1988; Statzner & Higler 1985; Ward & Stanford 1983, 1988) suggests that this hypothesis must be expanded to incorporate resets in biotic communities brought about by sudden nutrient inputs from lakes, tributaries and marshes draining into a river. The original R.C.C. does not take into account alterations in community structure that do occur at these reset locations. The modified R.C.C. proposed by Sedell and Richey (1988) and the S.D.C. proposed by Ward and Stanford (1983) do account for the existence of these transition points. Further resets and inputs of nutrients occur laterally during peak discharges when large amounts of nutrients enter the stream from the riparian zone and floodplain. Cummins et al. (1984) suggest that the riparian zone exerts primary control over biotic association. Control is mediated both through physical channel influences (i.e. solutions or particles) from outside the wetted channel or instream plant growth. These corridors are believed to be inseparable from the biology in the channel and constitute a "ribbon of continuity" responsible for many universal discernible biotic assemblage patterns.

The interaction of the river with its floodplain is also critically important in defining its productivity. During a rise in flood water, water and nutrients flow into the floodplain, enriching the plain. As water recedes, nutrients and organic material are transported back into the river. It appears that the greater the magnitude and duration of a flood in a large floodplain river, the more productive the fishery (Welcomme 1979). As well, the greater the interaction with the floodplain and its vegetation, the more productive the reach of river (Halyk and Balon 1983; Hynes 1975; Sedell and Richey 1988; Welcomme 1979).

As well as floodplain interactions, other research suggests changes in nutrient spiralling and input occur at transition points aong the length of a stream. These points often occur at major slope changes (Statzner and Higler 1985) and act as major system resets demonstrating high biotic production and diversity.

4.3 Allochthonous and Autochthonous Material

Two primary sources of organic matter are found in stream systems. Allochthonous matter enters the stream from the surrounding land, whereas autochthonous matter is produced in the stream itself through photosynthesis. In small forested streams, shade reduces the amount of autochthonous production so that the major input of organic matter comes from the surrounding forest in the form of leaves in the autumn, seed and flowering parts in the spring, and branches, twigs, etc., throughout the year. This difference in importance is illustrated if aquatic community metabolism is examined using the ratio of the rate of gross primary production (P) and the rate of ecosystem respiration (R). In streams where organic matter from outside the stream predominates, the ratio of P/R is <1 and the system is referred to as heterotrophic. In streams where primary production is greater than or-

ganic matter respired in the stream, the ratio of P/R is <1 and the system is referred to as autotrophic.

Allochthonous matter can take the form of either dissolved organic matter (DOM: will pass through 0.45 um filter), fine particulate organic matter (FPOM: <1 mm diameter) or as coarse particulate organic matter (CPOM: >1 mm diameter) matter. DOM can enter the stream directly or through leaching from particulate matter. Whatever its origin it plays a significant part in the energy flow of streams (Kaushik 1981). Particulate organic matter (POM) entering a stream can release its component of DOM quickly. The POM remaining, depending upon its type, is quickly colonized by microbes and subsequently utilized by aquatic invertebrates as a very important component of their food sources.

Very coarse POM entering a stream can provide many benefits. Coarse matter in the form of logs and trees can shape and change the channel form of the stream and assist in channel stability. (Benke et al. 1985; Bilby 1984a; Sedell and Richey 1988). Historically, CPOM has shown to be very important in controlling channel diversity and invertebrate and fish production (Benke et al. 1985; Conner and Naiman 1984; Sedell and Froggatt 1984). Modest amounts of CPOM can create debris dams which also serve to trap finer POM moving down the system. These debris dams serve as refugia for invertebrates, and as traps for sediment and nutrients. This appears to be the case for exceptionally high gradient rivers in the Pacific Northwest (Bilby 1981, 1984a. 1984b).

The R.C.C. hypothesizes a gradual shift from heterotrophy to autotrophy as stream order increases from order 1-3 to order 4-6 (Fig. 2) (Vannote et al. 1980). This shift, in part, reflects the decreasing effect of forest shading on streams. The R.C.C. hypothesis has been recently modified to indicate that allochthonous matter can be very important in large rivers with floodplains and provide key controls on nutrient spiralling, channel morphology and fish habitat (Benke et al. 1985; Conner & Naiman 1984; Cummins et al. 1984; Sedell & Richey 1988; Ward & Stanford 1988). The lateral movement of water into the floodplain and its movement back into the channel brings enormous amounts of allochthonous matter into the river channel. The finer matter can be processed by the aquatic community while the larger material plays a role in channel alteration and stabilization. This is contrary to the original hypothesis of the R.C.C. which indicated that autochthonous matter was likely to be the most important organic matter component in larger rivers. Therefore the riparian zone exerts the primary control over biotic associations mediated physically through channel influences, and biologically through the nature of the organic input from outside the wetted channel (allochthonous) or instream plant growth (autochthonous).

5.0 Fish Community Dynamics

Fish populations have adapted their life history strategies to complement the functioning of natural river systems. Habitat requirements can be subdivided into physical, chemical and biological components. The physical conditions required include living space in the form of water quantity, a diverse river channel which provides a diversity of habitats for all life stages of the species and suitable living space for cover and growth. Chemical requirements include suitable temperature regimes for the particular species, well oxygenated water, moderate pH range, dis-

solved solids, etc. Biological requirements include a suitable and diverse food source and stable community structure.

Certain features of rivers can control and enhance production of fish. In most species, critical life stages occur which act as a bottleneck for recruitment of fish to the adult population (Regier et al. 1988). Habitat for these critical life stages include habitat for reproduction, nursery areas and overwinter habitat (in temperate climates). Historically, an abundance of these habitats occurred in natural systems through a highly diverse but stable channel morphology (Sedell and Luchessa 1981; Sedell and Froggatt 1984). Various research has shown that anything that increases the amount of edge cover along a channel (e.g., forested islands) and enlarges the channel capacity (i.e., floodplains, side channels) increases the productivity of the system (Gosse 1963; Hynes 1975; Welcomme 1979). This emphasizes the critical importance of the floodplain/riparian interactions to the stream's productivity. Even in medium order streams floodplains are critical reproductive and nursery habitats for fish (Halyk and Balon 1983). In large rivers such as the Amazon, virtually all fish production occurs in the floodplain (Bayley and Petrere 1988; Malvestuto and Meredith 1988; Welcomme 1979, 1988). Historically diverse river channels and floodplains explained the enormous production in west coast rivers (Northcote and Larkin 1988) and rivers in Europe (Lelak 1988). Further evidence of the adaptation of fish to floodplains can be seen in the timing of riverine fish species reproduction migrations, incubation and rearing periods. If these periods are compared to peak annual discharge events, they are found to be associated (Welcomme 1986).

The R.C.C. predicts that as river order increases a shift occurs in feeding strategy of fish from invertivorous/pissivorous to plankivorous (Vannote et al. 1980). The concept has been modified to take into account serial discontinuities and natural readjustments in rivers which have the effect of shifting feeding strategies in either direction, depending upon the reset mechanisms. Sharp increases in gradient with increase in coarse material in a system may alter the plankivorous fish community in a large river to a community made up of invertebrates and piscivores (Ward and Stanford 1988). A flip-flopping of conditions could reset a fish community several times in a large system that includes natural or artificial lakes and major changes in gradient and nutrients (Statzner and Higler 1985). Several researchers have suggested that major geomorphological transition zones are often the sites used by many fish species for critical life history stages such as spawning and nursery habitat (Regier et al. 1988; Sedell and Richey 1988; Statzner and Higler 1985).

6.0 Summary

The shape, character and nature of rivers are controlled by geology and climate, and modified by mechanisms of soil composition, riparian vegetation, and local climate. Biotic communities adjust rapidly to changes in the redistribution of kinetic energy by the physical system.

The development of integrating hypothesis such as the R.C.C. and S.D.C. have provided a framework for the examination of the physical form of the catchment and its effects upon channel shape, slope and biotic productivity. It is obvious that the stream ecosystem is the final integrator of the physical, chemical, and biological nature of the catchment. This integration works to maintain a dynamic stability in spatial and temporal dimensions. This stability may be viewed as a tendency to reduce

fluctuations in energy flow over space and time in the face of instability in the physical system (Sedell and Richey 1988).

Linkages occur between shape and structure of a river, its biotic community and its riparian vegetation and floodplain. Although geology and climate dictate the general character of a river, the riparian zone modifies and controls channel shape, pattern, nutrient input and spiralling, heterotrophic vs. autotrophic conditions, and the nature and abundance of the biotic community. The need to understand these relationships and their effect on energy utilization is essential if we are to manage rivers for all uses.

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Demand Management Of Stream Angling Resources

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Introduction

Manipulation of supply has been the dominant philosophy in the management of water resources, while much less attention has been given to management of demand (Robinson et al., 1984; Tate, 1984). This has been the case across many water uses, for example municipal water supply, and also in the context of recreational use of water resources, including stream angling resources.

In recreation, a traditional response to demand - supply imbalances has been to increase the supply of opportunities available, for example through expansion of park systems or acquisition of riparian land, or to manage the resource more intensively from a biophysical perspective by stocking streams with sport fish or rehabilitating habitat for particular species.

The Ontario Ministry of Natural Resources is presently encouraging local involvement in improving sport fisheries through the Community Fisheries Involvement Program. Supply management, while necessary and important, is becoming increasingly constrained. Demand for stream angling opportunities in southern Ontario remains very strong, but the costs of acquiring additional public stream angling resources are escalating. Public access to private riparian land in parts of southern Ontario is becoming increasingly limited by landowner posting (Lee and Kreutzwiser, 1982).

In contrast, demand management has as its principal objective maximizing efficiency and effectiveness in utilizing existing resources. In the context of municipal water supply, demand management utilizes various economic, regulatory and technical mechanisms for reducing water use. In recreation, demand management attempts to maximizing the benefit to users of existing resources. But in both instances, emphasis is on behavioural aspects of resource use.

The call for greater emphasis on demand management of water resources, including stream fisheries, is not new. The American Water Works Association, for example, has promoted the adoption of various water conservation strategies since the mid 1970's (AWWA, 1981). Even earlier, Wagar (1964) suggested the application of a behavioural approach to the management of engineers and natural scientists, whose training does not stress behavioural aspects of resource use, may be a contributing factor.

While aspects of supply management will remain important, for example protection and rehabilitation of stream habitat, this paper argues for greater application of demand management. Its objectives are to: 1) describe the demand management concept in the context of stream angling resources and 2) illustrate the relevance of this concept to management of the Upper Credit sport fishery in southern Ontario.

Demand Management of Recreation Resources

Demand management of recreation resources, often referred to as experience-based setting management (Manfredo et al. 1983), assumes a behavioural interpretation of recreation. Recreation is seen as an experience derived from participation in particular activities in particular settings.

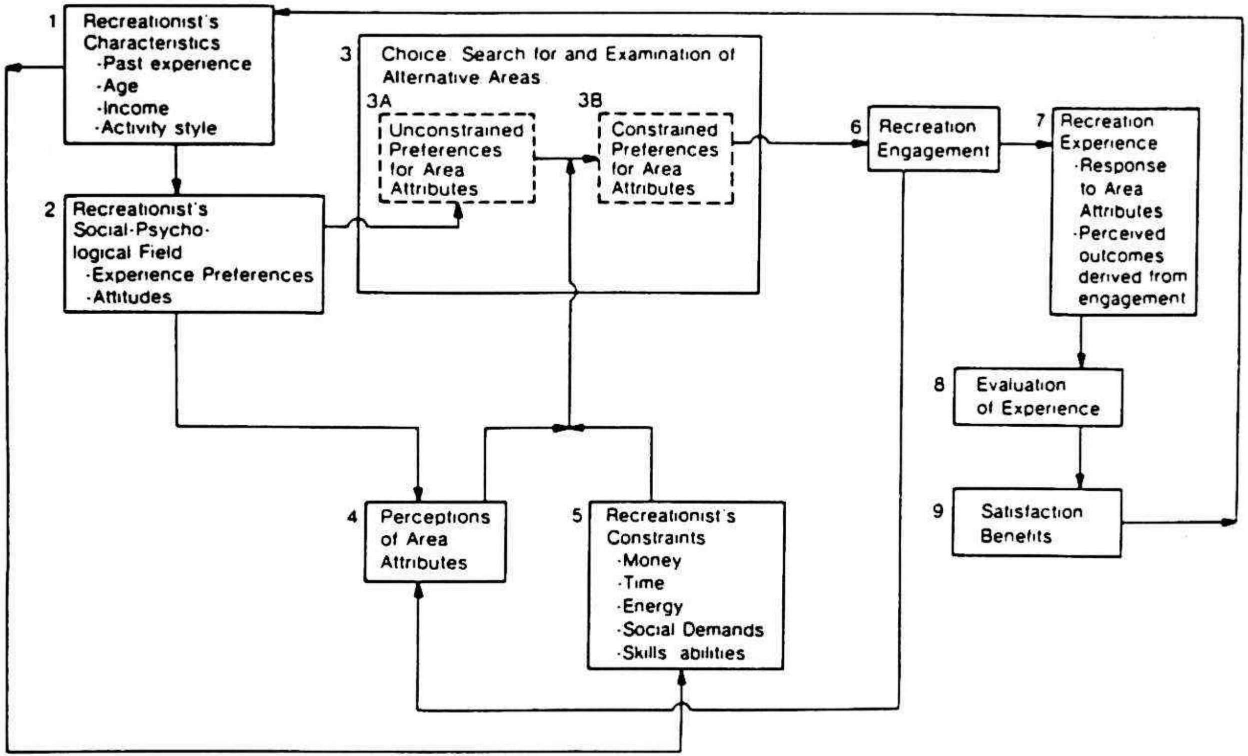
Briefly, Figure 1 represents a model of recreation choice in which a potential recreationist with distinguishing characteristics, attitudes and preferences for particular experiences chooses a specific site for his recreation engagement. The extent to which the recreationist benefits from the engagement will be a function fo the degree to which desired and expected experiences have been provided by the engagement at the chosen site. An elaboration of this behavioural model can be found in Harris et al. (1985) and Driver (1976). Various empirical tests of this model have shown that recreationists, even those pursuing essentially the same activity, will differ in the experiences sought and preferences for how settings should be managed (Manfredo and Anderson, 1982). Thus, demand management encourages managers to examine closely the desired experiences and management preferences of recreationists and to allocate and manage resources to maximize the probability of achieving satisfying experiences.

Fishery Management Attitudes of Upper Credit Anglers

To further illustrate the utility of the demand management or behavioural approach, 242 anglers using the Upper Credit River were interviewed during the April 24 - September 30, 1982 angling season. The study area is a 21 km portion of the Credit River from Cheltenham to Alton (Figure 2) and has been identified by the Ontario Ministry of Natural Resources as an important salmonid fishery, particularly for resident brown trout. The importance of this sport fishery is reflected in recent attempts by the Ontario Ministry of Natural Resources and Credit Valley Conservation Authority to improve habitat and acquire some riparian property (Figure 2).

Details on the methodology can be found elsewhere (Kreutzwiser 1984), but briefly respondents were asked to provide information on their socio-economic and angling behavioural characteristics and to respond to a series of Likert statements concerning their perception of selected fishery management problems and potential managerial responses to these problems. Each statement was accompanied by a five-part agreement - disagreement scale and responses were scored from 1 (strongly agree) to 5 (strongly disagree). Tests of differences in mean agreement-disagreement scores were used to determine which of a number of hypothesized variables discriminate management attitudes. These discriminating variables were further examined as to their relative importance using a grouping algorithm known as Automatic Interaction Detector (AID). AID breaks down a set of observations on a continuous dependent variable (agreement - disagreement score) through reference to a set of nominal independent or discriminating variables. All respondents are first split into two groups on the discriminating variable that maximizes the between group sum of squares. The subgroup with the largest within group sum of squares is then subdivided and so on, producing a set of mutually exclusive subgroups which can be arranged in a tree portraying the relative importance, rather than statistical significance, of discriminating variables.

FIGURE 1: A BEHAVIOURAL MODEL OF RECREATION CHOICE



Source: Harris, Driver and Bergersen, 1985

Fishery Management Attitudes

Crowding was not perceived to be a problem by the majority of Upper Credit anglers; only 35% of respondents agreed that too many fishermen was a problem. A majority of respondents (60%), however, agreed that gaining access to the Upper Credit was a problem. This likely reflects some landowners posting riparian property "no trespassing".

Attitudes toward possible managerial responses to crowding and access reflect perception of these problems. A majority of respondents (65%) disagreed that restrictions should be placed on the number of anglers using the fishery at any one time. However, over 70% expressed a willingness to pay government or landowners to gain more fishing access to the Upper Credit.

Stocking, habitat management, fishing gear restrictions and catch and release regulations are supply and demand management tools that have been applied to a number of fisheries and have been debated by anglers and fishery managers. Habitat management, stocking and some gear restrictions have been used on limited sections of the Upper Credit. Respondents were divided as to whether stocking or habitat management was the most appropriate means of enhancing the fishery. However, only 23% of respondents agreed that the Upper Credit should be stocked with migratory rainbow rather than resident brown or speckled trout. A majority of respondents (63%) agreed a catch and release regulation should be imposed, but reaction to restricting specific sections of the Upper Credit to particular types of fishing was more divided. Only a 2 km stretch of stream managed by Trout Unlimited and the Caledon Mountain Trout Club has been restricted to flyfishing.

Influences on Management Attitudes

Ten characteristics of anglers were hypothesized to be related to management attitudes. Included were the following behavioural attributes: type of fishing gear used on the interview day (spin-cast, spinning, fly), number of days fished on the Upper Credit the previous year, preferred angling setting (lake, river, stream, no preference), setting specialization (anglers reporting at least 90% of the previous year's angling-days in any one setting were considered specialized), and interview location (upper, middle, or lower portion of the study area). Also included were the following socio-economic characteristics: age, education (secondary school or less, post-secondary), household income, and occupation (office, manual, other).

T tests were used to identify significant differences in mean agreement-disagreement scores for each attitude statement between groups of respondents distinguished in terms of each of the above hypothesized discriminating variables. Figure 3 shows that a majority of the differences in attitude scores are attributable to angling behavioural rather than socio-economic characteristics. Days fished last year and interview location are especially notable in this regard. Days fished on the Upper Credit, setting preference and education are significant discriminating variables in over half the attitude statements as well. Fishing gear was a factor in three of the most controversial statements.

Flyfishermen, better educated anglers, those preferring a river or stream setting, fishing more frequently and using the middle section of the study area preferred habitat management to stocking and favoured restricting specific sections of the Upper Credit to particular types of fishing. Respondents with these attributes dis-

FIGURE 2: THE UPPER CREDIT STUDY AREA

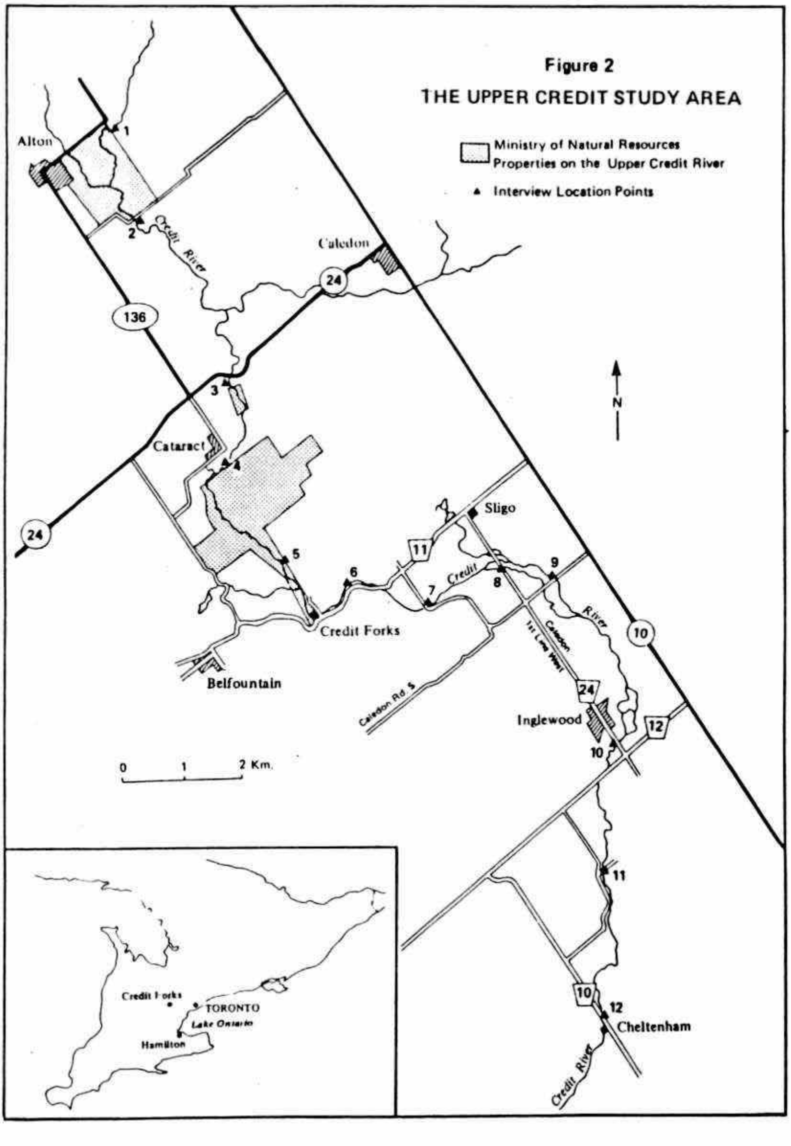


FIGURE 3: SUMMARY OF T-TESTS

ATTITUDE STATMENT	days fished last year	interview location	days fished Upper Credit	setting preference	education	income	occupation	fishing gear	age	setting specialization
Crowding is problem	X		X							
Numbers should be restricted										
Access is a problem	X		X							
Rainbow rather than resident trout should be stocked	X	X	X	X	X			X	X	
Catch and release should be enforced		X		X	X		X			
Sections should be restricted to types of fishing	X	X	X	X	X	X	X		X	
Parking and other facilities are needed		X		X			X			
Stocking rather than habitat management is best	X	X		X	X	X	X	X		
Willing to pay for access	X	X	X		X	X			X	

X mean attitude score significantly different at 95% confidence level.

agreed that rainbow rather than resident brown or speckled trout should be stocked.

AID analysis was used to show the relative importance, rather than statistical significance, of discriminating variables. Figure 4 illustrates for one attitude statement groupings of respondents generated by the first three splits. In this illustration, type of fishing gear used was the most important variable distinguishing opinion on the statement "several specific sections of the Upper Credit should be restricted to particular types of fishing". Flyfisherman constitute one subgroup in strong agreement with this statement while those using spinning and spin-casting gear formed a second subgroup in some disagreement. Within group variance was greatest in the latter group, which was subsequently split on the basis of interview location (section of study area used).

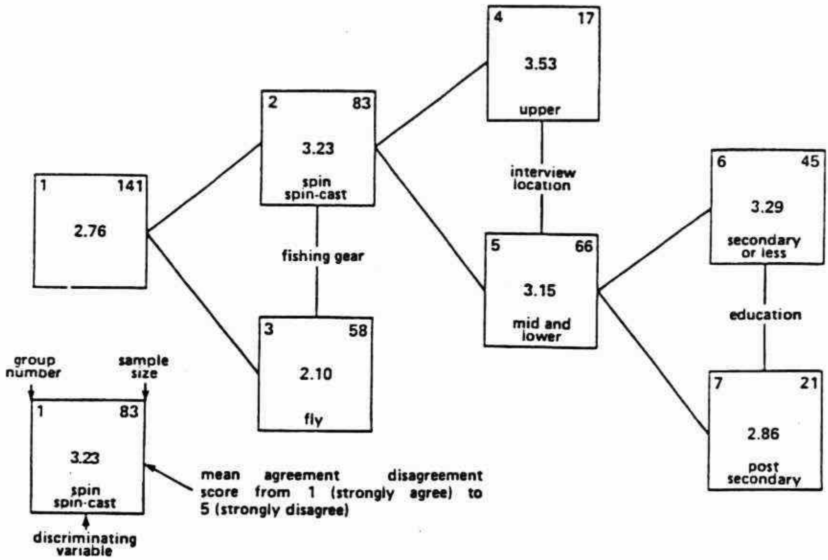
Figure 5 shows the three most important discriminating variables for each attitude statement. Of note, type of fishing gear used generated a first split more often than any other variable.

Implications

The Upper Credit study yields managerially useful information and provides support for the demand management philosophy in the content of stream angling resources.

Little support for restricting numbers of anglers using the Upper Credit at any one time is evident, while a catch and release regulation apparently would be supported.

FIGURE 4: SEVERAL SPECIFIC SECTIONS OF THE UPPER CREDIT SHOULD BE RESTRICTED TO PARTICULAR TYPES OF FISHING



Opinion on these potential management tools cuts across all socio-economic and behavioural characteristics. However opinion on stocking, habitat improvement and zoning specific sections of stream for particular types of fishing is highly polarized. Flyfisherman stand out as group strongly favouring habitat improvement and restricting sections of stream to specific types of gear. Zoning of angling uses offers the potential of a more efficient and effective allocation of limited angling resources and, while an aggressive response which raises some concern about fairness of access, the locus of support for it is clear.

The results also provide a basis for anticipating potential controversies. For example, any extension of migratory rainbow trout into the Upper Credit with accompanying biological threat to the resident brown population will be met with strong opposition from flyfishermen.

A significant implication of the Upper Credit study and related literature is that specific groups of anglers (or other recreational users of stream resources), with different experience, setting and management preferences, can be identified. An understanding of these differences is a valuable complement to more traditional management of stream angling resources, with its reliance on manipulation of the resource.

FIGURE 5: SUMMARY OF AUTOMATIC INTERACTION DETECTOR ANALYSIS

ATTITUDE STATEMENT	1st SPLIT	2nd SPLIT	3rd SPLIT
Crowding is a problem	income	days fished Upper Credit	education
Numbers should be restricted	education	interview location	days fished Upper Credit
Access is a problem	occupation	age	income
Rainbow rather than resident trout should be stocked	fishing gear	occupation	education
Catch and release should be enforced	occupation	setting preference	days fished last year
Sections should be restricted to types of fishing	fishing gear	interview location	education
Parking and other facilities are needed	interview location	interview location	fishing gear
Stocking rather habitat management is best	fishing gear	age	education
Willing to pay for access	days fished Upper Credit	income	fishing gear

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Economic Issues Of Water Demand Management: Their Application To Municipal Water Use

Donald M. Tate

The Inquiry on Federal Water Policy (Pearse et al.) identified several areas of water management where new or renewed strategies are required to meet future needs. One of these areas was water demand management, a theme that was developed in several sections of the inquiry's report. My paper today examines the subject of water demand management, defined here as a group of water management strategies that reduce or reschedule average or peak withdrawals from surface or groundwater sources while maintaining or mitigating the extent to which return flows are degraded (Marbek, 1987, p. 1.4.).

On the demand side, such strategies include installation of water meters, appropriate water pricing, the payment of full costs of water use by beneficiaries, and the charging of fees or penalties for the discharge of pollutants into receiving waters. Demand management also includes a range of physical alterations to the way in which water is used, such as flow restrictors, process and water system alterations, renovation of water supply and treatment infrastructure and improvements to water conveyancing in irrigation.

To develop the water demand management theme in this paper, I intend to concentrate on municipal water use, which, although not the largest category of use, is certainly one of the most important. The link joining this paper to this symposium's main theme is that municipal water uses often form vital components of water management at a river basin level. In most provincial priority listings of water use, for example, domestic uses, mostly centered in municipalities, usually occupy first place. In using municipal water use as an example, I must emphasize that water demand management can affect all types of water use, and will be important in the management of water problems in other sectors of the economy.

Basic Facts about Municipal Water Use

In 1983, the average daily flow of all municipal water utilities in Canada serving populations over 1,000 persons totalled 12.4 million cubic meters (MCM) (Tate and Lacelle, 1987). Ninety percent of this total (11.1 MCM) was provided from surface water sources, with the remainder from groundwater. The latter source was used predominantly by smaller municipalities. Return flow, defined as measured intake to waste treatment facilities, totalled 7.6 MCM for the average day, or 61% of in-

1. The opinions expressed here are those of the author alone, and not necessarily those of Environment Canada.

take. The 39% of pumpage not accounted for includes several categories of use, such as untreated flows discharged directly to ambient water courses, fire flows, evaporation as a result of lawn and garden irrigation and system leakage. Although precision is not possible, it is estimated, based upon studies carried out in the past (eg. Prairie Provinces Water Board, 1982) that at least 20% of this figure is attributable to leakage from distribution systems and other forms of "wastage".

Municipal water use Canadian style has two systematic and pervasive attributes: cheapness and wide variability in per capita use amongst municipalities, even of comparable size and regional location. For example, water use per capita in Calgary is twice that of its sister city, Edmonton, according to data collected for 1986 (Environment Canada, Water Pricing Database,1986). Moreover, water use in Calgary grew much faster than in Edmonton over the 1983-1986 period (Environment Canada, 1986, Municipal Water Use Database). Water rate structures vary markedly between the two cities, with Calgary predominantly on a flat rate and Edmonton on a fixed block rate.

Table 1 Typical Prices for Popular Liquids

	A. Beverages	Cost ($/cubic meter)
	Tap Water	0.47
	Coca Cola	787.00
	Milk	900.00
	Perrier Water	1,333.00
	Beer	2,000.00
	Wine	6,000.00
	Whisky	18,000.00
B.	Gasoline	500.00

1. Based on charges in the Regional Municipality of Ottawa-Carleton for water supply ($0.34 per cubic meter) and sewerage ($0.13 per cubic meter). Note that all beverages except water have to be collected by the consumer, whereas water is delivered to the home and wastewater is removed at no inconvenience to the consumer.

Source: Environment Canada, Environment Protection.

Municipal water rates across the country are exceptionally low, as shown by the table before you now on the costs of typical liquids to consumers. Paradoxically, in view of these low rates, a problem of paying for municipal water infrastructure renovation has arisen, as shown, for example, in the 1985 by the Federation of

Canadian Municipalities (FCM,1985). This study recommended developing a fairly massive public subsidy program to solve the infrastructure aging problem.

In terms of domestic use per capita, Canadians are relatively high water users, exceeded in the selected listing of Table 2 only by the United States. The per capita usage across Canada shows significant spatial variation, from lows of around 250 liters per day in the semiarid Western interior to high, of over 500 liters per day in some areas of Atlantic Canada.

Table 2 Municipal Domestic Use (liters) by Selected Country, 1983

Country	Pumpage per capita-day
United States	425
Canada	360
Sweden	200
United Kingdom	200
West Germany	150
France	150
Israel	135

Source: For all countries except Canada, Postel, 1985, p. 40
For Canada, Tate and Lacelle, 1987, Table 3.

Current and Emerging Problems

Canadian municipalities currently face a number of serious, interrelated problems concerning water related infrastructure. Many of the water supply systems predate World War II, especially in the larger urban centers. With postwar economic and population growth, public agencies were under increasing pressure to provide funds for construction of adequate waste treatment facilities, resulting in the federally sponsored CMHC municipal infrastructure assistance program. The federal government alone spent some two billion dollars on this program of low interest loans and grants to municipalities, and substantial improvements resulted, principally to waste treatment infrastructure.

Since the demise of this program in 1978, a demise caused partially by the wish to have the federal government vacate an area of essentially provincial jurisdiction, much less effort has gone into municipal infrastructure funding. Available capital has instead been devoted to recreational facilities, municipal arts centers and the like. While no one is passing judgement on these expenditures, they have been made at the expense of maintaining basic services, which are now in increasing states of decay.

The need for renovation and upgrading applies to treatment facilities installed within the last 25 years, but even more to water supply systems, which tend to be

of pre-war vintage in many areas treatment facilities. One piece of evidence for this need lies in the large volume of municipal water pumpage which cannot be accounted for in return flows, which suggests substantial system leakage. This renovation will be a costly undertaking. The Federation of Canadian Municipalities study referred to above estimated that six billion dollars, later raised to 7.5 billion, would be required to improve the water related parts of municipal infrastructure. This may be a low-side estimate.

Concurrent with this need, the fiscal positions of senior levels of government have deteriorated from the 1960's. Spending on an array of public programs has created substantial government deficits, a rapid expansion in the national debt and a climate of fiscal restraint. Recent speeches by the federal Environment Minister, for example, make clear that there is little likelihood of a major federally sponsored municipal infrastructure program like the former CMHC program. Federal assistance is available through other programs, but as stated, a dedicated municipal infrastructure program seems unlikely. Thus, at a time of acknowledged need for large expenditures to improve water and wastewater systems, senior governments are hardpressed to find the required funds.

These economic and financial problems are heightened by a greatly increased public concern for the environment, which consistently registers among the top concerns on public opinion polls. Increasing volumes of waste, the concern about toxic chemicals in drinking water supplies and deteriorating systems have combined to create this increase in public concern.

The Role of Water Demand Management

Water demand management offers both a diagnosis and a number of potential solutions to these problems. The diagnosis relates to low prices for municipally supplied water. In a 1983 study, my colleagues and I found that municipal water prices throughout Canada were very low, as reflected in Table 1, badly structured and consistent with the promotion of high water use (Tate, Reynolds and Dossett, 1983). More recent surveys have confirmed these findings. For example, the total cost of 20,000 liters of water per month, an average usage for a Canadian residence, ranges between \$5 and \$20, often substantially less than a case of beer!

In addition to low prices, water rate structures throughout Canada promote water wastage. In 30% of municipalities, water charges take the form of flat rates, under which consumers pay a fixed amount for as much water as they use. This means that consumers have absolutely no incentive to conserve. Flat rates normally pertain to municipalities with unmetered water supplies, although they are also quite common in metered municipalities. The next most common rate structure is termed a "declining block rate" structure. Under this type of system, water usage is divided into a number of blocks, or volumes, of water used. Rates are set for each block, which decline progressively as users move into higher blocks of the structure.

This system, according to proponents, even professional groups such as AWWA, is justified by the fact that everyone should share the fixed system costs, and therefore such costs have to be levied in the first blocks of the structure. Large water users, having paid their share of fixed costs in the initial blocks, thus face lower charges in the upper blocks of the structure. In other words, the more water consumers use, the less they pay per unit—again a disincentive for water conserva-

tion. This disincentive has arisen through the interesting juxtaposition of finance and economics.

Other types of rate structures, such as level block rates, the system advocated as a reasonable approach by Hanke (1978), or increasing block rates are comparatively rare throughout Canada. Surveys of water rates continue to find an extremely varied set of practices, including cost recovery though assessment, rate based upon the number of plumbing fixtures, and so forth. We even found one area where the number of horses kept could form part of the rate determination!

Low water prices and the predominant Canadian rate structuring practices have substantial effects on municipal water use. Looking first at a static situation, consumers receive the wrong signals about the value of water used—that it is a cheap commodity which need not be conserved. Thus, water is viewed as a requirement to be met, not as a demand which can be changed through pricing practices. Artificially high demands mean that operating and maintenance costs, including energy costs, are inflated. Prices fail to reflect the true costs of system construction, maintenance and renovation. The deteriorating condition of water related infrastructure is proof of this . Declining block rates or, even worse, flat rates fail to recognize that the large water users are basically responsible for overall system capacity, design and costs. Thus, in reality, they are implicit subsidies to large water users from the general public.

In a dynamic situation, the effects of low prices are compounded. Because they are low, prices are rarely taken into account in projecting water demands. Consultants and analysts assume a constant, of even *increasing* water use per capita, and then multiply these "coefficients" by projected population to generate projected water "requirements" in the future. These requirements then become design parameters, and lead to systems being expanded or built that would be too large if water prices were more reflective of actual resource values. These systems, being in place, have to be used, which forms an incentive for keeping prices low. Thus the cycle of low prices high demands over building is self reinforcing. What is more, it is, quite probably, wasteful of scarce public capital.

My inference from these facts is that water prices should rise - even a doubling or tripling of current prices would not be out of line, in view of the very low level of current prices. I don't intend here to develop the theoretical justification for this claim. I merely point to the common sense observation that as prices rise, demands fall. This happened when energy prices rose, albeit in the midst of a great wringing of hands. The same thing will happen with water, which is viewed as an essential service, much like energy once was. Further, let me relate to you an interesting statistic. At todays level of usage, estimated at 4,800 MCM per year, a rate increase of 42 cents per cubic meter would raise $12 billion over 5 years, assuming no drop in demand. This works out to less than $5 per capita month over five years. Even with a decrease in demand of 25%., this not unreasonable doubling of price would raise enough to fund infrastructure renovation.

The Potential Effects of Demand Management

In concluding the paper, what can be said about the potential consequences of water demand management for public utilities? Severe potential problems in financing, water supply and water quality appear to be emerging in sector, problems which will require long term commitments of billions of dollars. Thus, it is impor-

tant that all water management options be examined carefully, so that the most efficient solutions can be found. Water demand management offers some positive outlooks and suggestions for dealing with these problems.

The thesis presented here is that, for any substantial progress to be made on handling the problems of municipal water use, universal water metering coupled with significant increases in water prices are two fundamental steps in rationalizing municipal water use and raising the funds necessary for infrastructure renovation in a relatively painless manner and without an inordinate debt load on public treasuries. Prices are the key signals to consumers and planners as to the value of the resources, and, as shown above, the traditionally low municipal water prices have reflected a substantial undervaluing of the resource. More realistic water pricing practices, I believe, are the key to better, more efficient municipal water management in the future.

Several effects would follow such a price rise. In the short run, water usage, on average, would fall in varying degrees depending upon the size of the price increase and the price elasticity of demand. Most figures indicate an initial decline in water usage of 25% or more, with a rebound, as users adjusted their water use habits, to a longer run decrease of 15-20%. Various means, such as retrofitting of plumbing fixture and other conservation measures outlined earlier would be the means for reducing water use. Some short term revenue shortfalls might result, calling for temporary financial assistance to municipalities, but this should not be allowed to interfere with the long term movement to more rational water use. With more rational water pricing in place, demand forecasts would be lowered, thereby delaying or even postponing the need for infrastructure expansion. Lower operating and maintenance costs would result, including decreased energy costs as less water would be treated or pumped, and waste treatment needs would fall. Higher water rates, assuming price elasticities less than 1, would generate needed capital for infrastructure renovation and improvement. Geographically, urban centers might become more concentrated as new developments became responsible for the full marginal costs of water supply. Finally, higher municipal water rates would induce industries connected to the municipal system to institute water conservation measures, resulting in decreased system demands and reinforcing the trend to lower residential water use.

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Economic Methodology in Watershed Planning and Management

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Introduction

Formal requirements for economic analysis of water resource projects are limited in the Province of Ontario. Conservation Authorities must now include benefit-cost statements in support of project plans filed with the Ministry of Natural Resources (MNR), while under the Drainage Act (R.S.O. 1980, ch 126), a benefit-cost statement can be required in support of petitioned drainage works. In both cases, guidelines are available for completion of the benefit-cost statement (Irwin, 1975; Strelchuk, 1983). Beyond these requirements, both the Conservation Authority Act (R.S.O.,1980, ch 85) and the Drainage Act require the apportionment of project costs on the basis of benefits to affected parties while the Environmental Assessment Act (R.S.O., 1980, ch 140) requires "an evaluation of the advantages and disadvantages to the environment" of a proposed undertaking and its alternatives. These stipulations could be addressed using formal economic concepts though this is not a requirement.

The benefit-cost analysis guidelines mentioned above deal with a restricted set of methodologies within a narrow planning context. More comprehensive methodological guidelines are available from the federal government. Two documents from the Treasury Board (1976, 1982) provide a more detailed account of benefit-cost analysis and related methodologies but do so within a very broad framework of public sector planning. Water resources planning is the focus of an Environment Canada publication, "Monograph on Comprehensive River Basin Planning" (1976), which provides a broad discussion of economic methodology. However, this discussion is concerned with a specific type of planning exercise, the comprehensive watershed study. Water resources planning, however, occurs at various levels, comprehensive planning exercises representing only one end of the spectrum.

It is also notable that all of the documents cited above discuss only evaluation methodologies. Evaluation is of course central to the role of economics in water resources planning, but the function of economic analysis in planning goes beyond evaluation.

The purpose of this paper is to provide a broad examination of economic analysis in water resources planning. A critical theoretical review of methodologies is not intended; rather, this paper examines the practice of economic analysis in water resources planning in Ontario by:

- Providing an overview of available economic methodologies,
- documenting the use of these methods in recent planning studies undertaken in Ontario, and

- evaluating the current role of economic analysis in watershed planning in Ontario.

The Planning Context

The context for this investigation is the water resources planning process. A generic characterization of the typical planning study assumes the following steps:

1. perception of issues/needs
2. setting goals and objectives
3. system description, problem assessment
4. development of alternative management actions/plans
5. assessment of impacts
6. evaluation and selection of preferred actions/plans.

Specific planning studies will adhere to this study blueprint to a greater or lesser extent depending on many factors including the policy and program environment, the planning issues, the study staff, and the intent of the study.

The planning process is not perceived as a discrete process that progresses systematically from issue perception to planning study to implementation. Rather, it is seen as an ongoing process involving formal and informal interactions between several agencies and jurisdictions. Within this process, the planning study may fulfill a variety of functions among which are scoping of problem and solutions, development of long range blueprints for action and providing inputs for funding approvals.

Taxonomy Of Economic Methodologies

The term "economic methodology" is interpreted loosely to refer to techniques that derive from our understanding of how agents in the private sector make decisions that bear directly or indirectly on water resource uses. Concepts such as scarcity, efficiency, equity, property rights, time preference, utility, profit, and welfare provide the under pinning for models that describe how consumers and producers behave, that predict how the economy functions as a whole, and that prescribe how public resource-use decisions should be made.

The functional classification of economic tools corresponds to steps of the planning process outlined above. Each of these steps has a significant economic dimension, however, in terms of planning methodology our discussion will focus on steps 3, 4, 5 and 6. Within these four steps, there are a range of methodologies that fulfill one or more of the following functions: description, economic evaluation, plan formulation and preference ordering. These functions are discussed briefly below while specific methodologies are outlined in the Appendix.

Descriptive Tools

The descriptive role involves the measurement of system attributes and the characterization of system processes in order to predict system response under various conditions. At the most basic level, description entails development of an inventory describing key variables such as land and water use, population, employment, types and levels of economic activity,income levels, etc.

Simple relationships between these variables constitute a first step in describing system processes. For instance, the ratio of water consumption to population in a

municipality provides a per capita water consumption rate that can be used in conjunction with opulation forecasts to predict futjure consumption levels. Similarly, multipliers that are used to predict income and employment generated indiectly as a result of project investments can be calculated as the ratio of income and employment associated with basic (i.e. export generating) and non-basic economic activities.

Such relationships are black box models. They are readily developed and applied but offer a limited capcity to investigate system behaviour.

Other more sophisticated models that describe system processes are also available to the practitioner. These include economic models of demand and supply for various marketed products and services, cost functions, financial and fiscal accounting models, input-output models and econometric models of economic systems. These have varying capabilities to predict the response of economic indicators, economic agents, and economic sectors to a variety of perturbations that are associated with water resource projects.

Economic Evaluation Methodologies

Descriptive tools such as cost functions, demand curves or input-output models can be used to generate monetary measures of impact. Such measures are the prerequisite for economic evaluation. While economic evaluation can be conceived of as a global evaluation strategy for final selection of management plans, in the context of this discussion, economic evaluation methodologies are assigned a more modest role; that of measuring the magnitude of a subset of project impact in terms of a common monetary yardstick. This subset includes direct and indirect project costs and benefits that are readily priced in the private sector as well as certain non-market impacts that can be assigned a hypothetical monetary value by virtue of their connection to market effects.

The connection of non-market impacts to market effects may be real or synthetic. In the case of a real connection, the non-market impacts are related to existing economic markets in a way that allows practitioners to examine the preferences for water resources amenities that individuals reveal by their economic behaviour. Thus, one may be able to analyse travel costs or real estate costs to evaluate certain environmental amenities. Demand curves for water-resource or water-resource-related commodities and services are an important input to this type of economic evaluation.

The synthetic connection is created by virtue of hypothetical contingencies that are posed in a questionnaire to elicit an evaluative information from individuals. Respondents can be asked, for instance, to select a tax level that they would willingly pay in order to clean up pollution. A forward looking variation of this approach addresses the question of willingness to pay to preserve future options that are at risk of being irretrievably lost.

Economic evaluation methodologies culminate in familiar techniques used to collapse various dollar measures into single summary values; namely cost-benefit analysis and cost-effectiveness analysis.

A common feature of both methods is their use of discounting to capitalize future monetary values. The principal distinction between them on the other hand is the treatment of benefits as well as costs in cost-benefit analysis, while with cost-effectiveness analysis, benefits are not assigned a monetary value. Both methods are

akin to the private sector financial analysis of investment options save that a social perspective prevails implying that all costs and benefits - private and public - must be incorporated into the analysis.

Salient issues in the exercise of benefit-cost and cost-effectiveness analysis are the choice of the discount rate and the treatment of price data when market values are not considered to be a fair measure of social value. When both benefits and costs are measured, the analyst must also be concerned with the manner in which these are summarized using either net benefits, the benefit-cost ratio or an internal rate of return.

Plan Formulation

Plan formulation may be a more or less complicated task depending on the scope of the watershed study and the resulting requirement for a management plan.

Typically, a planning exercise commences with a set of discrete planning options. For example, these may be engineering works, land use contriols, water resource pricing strategies, public information measures, grant programs, by-laws, and, of course, the do-nothing option. A management plan will comprise some discrete subset of compatible options.

Plans can be formulated in an informal manner relying on judgement and experience. However, for complex planning studies, programming methods are available to systematize the process. These use exclusionary criteria coupled with computer search routines to eliminate broad sets of inferior plans and thus to generate a manageable number of candidate plans. For instance plans may be required to attain certain goal achievement levels while minimizing cost or maximizing net benefit. Alternative plans are generated by altering constraint levels to capture varying levels of goal achievement or by modifying system parameters to reflect differing assumptions about system response.

In the process of plan formulation, infeasible and technically or economically inferior plans are eliminated. While technical judgements are necessarily made in this step, more subjective judgements reflecting preference are not meant to be used for screening purposes.

Preference Ordering

The phrase "preference ordering" is used here rather than a phrase such as "plan selection" in order to more clearly distinguish the role of the analytic procedure from the decision making function. Plan selection is the task of the decision maker(s) and must be based on the decision makers' perception of a preferred course of action.

Formulation of this perception entails a subjective judgement of what constitutes appropriate value and reasonable trade-off in the planning problem. The analyst may provide salient information on various preference orderings of alternative plans, but does not as a technical analyst make the subjective judgement regarding preference.

Preference orderings evaluated by the analyst may be those of the decision maker, of impacted stake holders or the public at large. They become technical information to be considered by the decision maker in the process of making a final decision.

The simplest methodology for preference ordering entails preparation of matrices that summarize technical impact and goal achievement data in units of measure

that implicitly or explicitly reflect value. Data on each impact or goal will imply a preference ordering in terms of appropriate selection criteria. The matrix serves primarily to organize technical information in an easily digested format.

Matrix data must be interpreted to derive a summary statement of preference. The tasks in this interpretation are:

A. transformation of technical data for each impact into explicit statements of preference across alternatives for that impact by scoring, scaling, rating, ranking, etc.

B. assignment of relative levels of significance to each goal and impact by weighting.

C. comparison and collapsing of value assignments across individuals or groups to derive a collective valuation.

D. comparison and collapsing of value assignments across impacts and goals to generate a preference ordering of plans.

Certain of these tasks can be fulfilled in an informal and intuitive process of group review and discussion. Alternatively, one or more of the tasks can be formalized using an explicit procedure.

In very simple studies with only one planning objective or selection criteria it is conceivable that an economic evaluation methodology such as benefit-cost analysis generates a complete preference ordering for alternative plans. The impact matrix is, in this case, a single vector of performance data and the interpretation of a preferred plan follows directly from that data.

For multiple-criteria planning problems, derivations of preference orderings for a given group of individuals can be based on various procedures. In group discussion techniques (Delphi, Nominal group), the four interpretation tasks are integrated and a preference ordering, if one is developed, evolves out of the structured discussion process. With various voting methods, Task C is undertaken as an explicit quantitative exercise, while other tasks are not formalized. In the limit, highly quantitative methods such as fuzzy set analysis formalize every task of the impact matrix interpretation.

Current Utilization Of Economic Tools

A functional hierarchy of economic tools is presented above, ranging from descriptive techniques through methods for economic evaluation and plan formulation to preference ordering methods. Techniques at each level tend to provide inputs to methods at higher levels. The methods vary greatly in complexity of structure and level of effort entailed in their application and provide decision makers with a wide range of potentially useful outputs.

In this section, we investigate the use of economic methodologies in recent Ontario water resource planning studies. Casual observation of water resources planning activity in Ontario quickly brings one to the realization that planning activity is a very heterogeneous process taking place within different agencies, under various policies and programs and for a variety of reasons. To help structure the discussion, planning studies that are reviewed here have therefore been grouped under one of three categories:

- single goal, single agency
- single goal, multiple agency
- multiple goal, multiple agency.

The review of studies is not meant to be comprehensive. It is more of a reconnaissance survey of selected studies in order to develop general impressions of methodological applications among different types of studies. A basic requirement of any study covered in the review was that it make recommendations related to water resources management.

Single Goal, Single Agency Studies

A number of studies reviewed within this category were prepared to obtain funding approvals. These were completed within programs with well defined requirements governing approach and content.

Flood reduction and erosion control measures proposed by Conservation Authorities must be supported by studies which contain benefit-cost statements, and a discussion of intangible impacts. Benefit-cost results tend to be closely scrutinized at the head office level and an overall scoring method is used in arriving at funding decisions. Standard cost curve methodologies are applied in evaluating flood damages for these studies, the cost curves in this case being the flood stage versus flood damage relationships for residential and nonresidential structures.

Engineering reports completed under the Drainage Act (R.S.O., 1980, ch 126) are similar to Conservation Authority project reports in that they must fulfill stipulated requirements for content. Standard methods are applied to allocate costs among watershed land owners according to outlet liability and benefits accruing to crop land. Benefit-cost statements can be requested for a petition drain and are required for a requisition drain. To our knowledge, the only benefit-cost statement formally requested under the Drainage Act was for the Reed's Bay Municipal Drain on Wolfe Island (Ecologistics Limited, 1983a). A benefit-cost analysis was completed addressing only tangible costs and benefits (significant intangible impacts were not anticipated). The preferred option was identified on the basis of net benefit.

Environmental assessment studies are another type of study characterized typically by a single sponsor (the proponent) and a single goal (as defined by the proponent). Under the Environmental Assessment Act (R.S.O., 1980, ch 140) a range of impacts must be assessed for the proposed undertaking and its alternatives.

Economic analysis is not specifically required under this act though class environmental assessment documents do provide more guidance in this respect. For example, the "magnitude" of positive and negative economic effects and the "economic affordability" of projects to expand or upgrade existing sewage or water systems must be described under Class E.A. provisions (Ecologistics Limited, 1984). The Class E.A. document for Conservation Authority water management structures requires cost-benefit analysis to aid in selection of the appropriate alternative (Association of Conservation Authorities of Ontario, 1986). Benefit-cost analysis was completed in three individual environmental assessments reviewed for this study. Two of these, undertaken under provincial legislation, used benefit-cost analysis to compare alternatives though analyses were partial in nature

(Ecologistics Limited and Totten Sims Hubicke Associates Ltd., 1981; Grand River Conservation Authority, 1978). The third study, of a cottage development on Shoal Lake (IEC Beak, 1983), was completed under Federal Legislation. It also contains a partial cost-benefit assessment but this is not used in a comparison of alternatives.

In addition to the studies outlined above that are related to approval programs, there are a large number of water quality assessment studies completed by the Ministry of the Environment. Many of these are technical assessments that do not offer recommendations on remedial measures, however certain reports do make such recommendations. A case in point is the Avon River study (Ontario Ministry of the Environment, 1979a). No economic analysis was done in this report, and recommendations were forwarded on the strength of water quality impairment assessments alone. In sharp contrast to this is a study by Donnan (1986) of remedial measures for mercury contamination on the English-Wabigoon River system. In this study both tangible and intangible impacts are discussed and a benefit-cost analysis completed for tangibles. Results of the benefit-cost analysis are used to support a recommendation against implementation of proposed remedial measures.

Single Goal, Multiple Agency Studies

Overlapping jurisdictions in water resources management often give rise to multiple agency participation in planning studies. This is particularly true of water quality studies in Ontario which may involve the Ministries of Environment, Agriculture and Food, and Natural Resources, as well as Conservation Authorities and Municipalities as major actors.

Our examination of several such studies revealed considerable variety in geographic scale and technical complexity across studies. The least complex studies were investigations of agricultural water quality impairment problems in smaller rural watersheds; examples include studies of Kintore Creek (Merkley ad Glasman, 1984). the Pittock Watershed (Anon., 1984a), the Ausable-Bayfield Watershed (Balint, 1984), Firella Creek (Grand River Conservation Authority, 1984) and the Rondeau Bay Watershed (Ecologistics Limited, 1983b).

The first three in this group are notable for their failure to use any economic methodology. However, these reports do not present or recommend specific remedial projects. Recommendations deal instead with the general need for remedial programs as well as the need for monitoring and further study. The Firella Creek study documents capital costs for specific measures and evaluates cost sharing arrangements for these costs. Measures are recommended even though no formal economic evaluation using cost-effectiveness analysis is presented. The Rondeau Bay study provided an evaluation of crop revenue impacts and capital costs of structures for representative farm operations but no overall economic evaluation and comparison of alternatives is made.

More complex watershed studies exhibited greater use of economic methodology. Four water quality studies of larger mixed urban/rural watersheds were investigated, these were for the Rideau River (Anon,. 1983). Lake Simcoe (Anon., 1985) the Avon River (Anon., 1984b) and the Humber River (Ontario Ministry of the Environment, 1986).

In these studies, recommendations were put forward regarding specific remedial actions after analyses that included assessment of costs (primarily capital), quan-

titative or qualitative assessments of water quality benefits and, screening to eliminate infeasible or inferior projects. Costs were expressed in present value terms and cost-effectiveness analysis was applied to some extent.

In none of the studies discussed above was there an economic evaluation of intangible impacts nor any attempt to use formal matrix algorithms or programming methods to assist in the decision making exercise. Recommendations dealt with individual remedial actions as well as programs for implementation, monitoring, etc.

Multiple Goal, Multiple Agency Studies

The two studies of this sort that were reviewed here fit most closely to the concept of the watershed planning process outlined above in that they progressed systematically from problem identification and description to final selection of a preferred plan. These studies, for the Thames River (Anon., 1975) and the Grand River (Anon., 1982), were both concerned with problems of water supply, water quality and flooding.

The Thames River Study differed from previously mentioned watershed studies like that for the Humber River primarily in its use of alternative comprehensive management plans as the basis for comparative evaluation. The economic methods however were similar to those in previously mentioned studies. They included estimation of the present value of project costs, partial benefit-cost analysis and tabulations of impact data. Public attitudes regarding proposed alternatives were considered but not analysed in a formal sense.

The Grand River Basin Watershed Management Study was notable for its extensive use of economic methodology. Principal methodologies applied in the study included linear programming and interactive decision models for plan formulation, voting and fuzzy-set procedures for analysis of public, staff and steering committee preference data, economic evaluation of certain intangibles and the use of partial benefit-cost analysis. Demand curves and cost functions were applied to generate economic data while plan formulation models were used interactively with engineering simulation models to fine tune management plans.

Discussion

An observation that follows directly from this brief review of Ontario water resource planning studies is that very little economic analysis is undertaken in most studies relative to the range of analyses that could conceivably be done. Several reports contained no economic analysis whatsoever while the majority provided only an incomplete documentation of project costs and the present value of costs. Certain reports contained results of partial benefit-cost analysis and an analysis of cost allocation. In only two studies was there systematic evaluation and screening on the basis of alternative management plans and only one of these employed a wide range of economic methodologies.

One might quickly conclude that more should be done to increase the level of economic information available to decision makers. The simple absence of such analyses however is not sufficient reason for recommending that more be done. In particular, more economic analysis would not necessarily result in an improved allocation of funds for water resources management.

To explore this issue further, one must first understand why it is that so little economic analysis is undertaken in practice. Certainly individual circumstances af-

fecting each study have a bearing; for instance factors such as the training and experience of study team members, the expectations of study coordinators or steering committee members and the study schedule and budget.

However, if we take a broader view of planning, such factors become endogenous to the planning process. That is, study team members well not have an expertise in economic analysis because such skills are not deemed necessary.

In this regard, while the planning process itself may follow, in a very general way, the planning steps outlined in the introduction (i.e. problem identification through to selection of a preferred plan of action), individual planning studies within the process do not generally appear to do so. All of the studies reviewed here commenced with problem indentification and some degree of system characterization. Some went from there directly to recommendations, others undertook to enumerate and describe alternative remedial measures, but only two appeared to be well-formed in the sense of following all of the steps that characterize a full planning study.

Why do so few planning studies adhere to a formula that on the surface appears so logical? Perhaps the answer lies in the nature of the planning itself. This is not a discrete activity functioning in isolation. It is, instead, a continuous function of the agencies involved in water resources management. Resource allocation decisions are made at various levels in different agencies within an institutional framework characterized by policy and program structures, administrative structures, and informal networks within and among agencies.

Most water resource allocation decisions of any consequence in Ontario encompass at least two levels of administrative authority and two or more agencies. The decision making process must therefore involve communication and consensus building function within and among agencies. Reporting, review and approval mechanisms and committee structures are means of fulfilling these functions.

Individual planning studies contribute to this communication and consensus building function, but, with the exception of comprehensive basin studies, individual studies are unlikely to produce the degree of consensus needed to facilitate implementation.

What appears to take place in most instances is that a series of studies is undertaken over time in response to a perceived problem. For example, water quality problems were identified on the the Avon River in the Thames River Basin Watershed Management Study. (Anon., 1975). This was followed first by a more detailed internal study by the Ministry of the Environment (1979a) and then by a more comprehensive watershed planning study (Anon., 1984b). Similarly the Lake Simcoe Environmental Management Study (Anon., 1985) was proceeded by at least two internal Ministry reports (1975; 1979b).

Within the context of this iterative study process individual studies, particularly earlier ones, will serve to foster a technical understanding of the issues, to establish agency positions and to identify the direction for further investigation. They will not necessarily lead to implementation. If this is the case, then a careful evaluation and screening of options is not essential in such reports.

It is only at a later stage, when planning reports represent a concerted interagency effort and are intended to lead to engineering design studies and implementation that the economic analysis component is paramount.

The extent of the economic analysis that is required will depend on the size and complexity of the study. Basic descriptive information that should be made available in all studies includes project capital and operating costs, cost allocations among stake holders, and impact data for evaluation criteria including intangible impacts and goal achievement indicators. This information should be summarized in a format such as the impact matrix and cost information should be expressed in present value terms using acceptable calculation procedures.

For studies such as those addressing local water quality impairment problems, benefits are accounted for via study goals which reflect Provincial water quality guidelines and objectives. In such studies, this level of evaluative information will usually suffice for purposes of identifying a preferred course of action. Of course in accepting this approach, one assumes that enough "wisdom" prevails in the process of setting and interpreting water quality policy that an acceptable balance of cost and benefit is implicitly achieved in the planning process. There is no empricial evidence to suggest that this is or is not the case.

Certain benefits are of course readily assigned a dollar value, namely benefits associated with engineering cost savings or flood and erosion damage reduction. Moreover we have seen that, for flood and erosion control measures, the policy framework necessitates benefit-cost analysis for proposed projects.

Should there be a similar policy for treatment of benefits in water quality or water supply studies involving significant investments? Certainly methods exist for the valuation of intangible water quality and water supply benefits. Some of these have been applied in a planning context during the GRIC studies (Fortin and Evans, 1981; Fortin and McBean, 1982). Whether such analyses are however necessary depends on whether they will have a fundamental impact on the planning process in the sense of altering the decisions that are taken and thus affecting the resource allocations that are made.

It was not clear that this was the case in GRIC. The benefits under consideration in that study related to flood reduction, water supply and water quality. Flood damage reductions were treated in a conventional benefit-cost framework.

Water supply benefits were evaluated using a consumer surplus approach. Resulting figures were input to the benefit-cost calculation and had a significant impact on net benefits. But the benefit numbers were, in this case, not "hard" numbers as were engineering costs and flood damaged reduction benefits; meaning both that they were uncertain estimates and that they were unfamiliar data. Conversely, there was never any real doubt that the benefits of achieving water supply goals would fail to justify anticipated costs. The salient planning questions for water supply were therefore to identify the cost-effective approach, and to evaluate incremental benefits or cost savings that could be realized from demand management.

In the case of water quality assessments in GRIC, related sport fishing benefits were estimated based, once again, on consumer surplus. In like manner the resulting numbers were certainly not hard, one could even call them ephemeral, given the many tiers of assumptions required to facilitate the valuation. But the exercise was completed, and it suggested that water quality benefits associated with sport fishing were negligible. The results were not used; instead, reference was made to established objectives and guidelines and to the intangible benefits implicit in these.

Had water quality benefits been more thoroughly and rigorously estimated in this study, and then used as the basis for decision making, the issue that could well have arisen might have been, "should any water quality improvement be made at all?", not "how much improvement is warranted?" It is not clear that a benefit-cost approach could have effectively addressed such a question given the uncertainties in benefit estimates and the limited geographic scope of the study.

At the provincial level, water quality improvement is a clearly established public goal supported by various government programs. Benefit-cost evaluations could conceivably help improve budget allocations among competing water quality improvement projects across the province, as it does for flood prevention projects. This would require development of a policy for systematic evaluation of water quality improvement projects. In the absence of such a policy, a piecemeal application of benefit-cost analysis in water quality studies would serve to increase the cost of such studies without necessarily improving the resulting allocation of public resources, or furthering the achievement of goals related to our water quality policy.

Methodologies that remain to be discussed deal with plan formulation and preference ordering.

Very few projects go through a systematic exercise of formulating alternative plans out of available remedial and mitigative options because in most studies analysts deal with a rather simple decision structure. More often than not, the planning decision involves determining which of several mutually exclusive options should be used or how many mutually compatible options should be adopted. The first requires a simple comparison of options while the second requires an evaluation of the incremental benefits and costs obtained from each successive option – both are option ranking exercises. Management plans comprising multiple options must be used for purposes of evaluation when multiple goals and significant system interdependencies cause the impacts of one option to depend on the presence or absence of other options. Such was the case in both the Thames and Grand River studies, and in only these was there a significant application of the management plan approach.

In the Thames River case, management plans were formulated without the benefit of programming tools. Programminng tools were used in the Grand River case but served primarily to help the study team develop a systems perspective of the planning problems. The programming tools were used to develop first-cut management plans but were too simple in structure to go beyond this. In the end, the task fell back on judgement assisted by interactive water resource "accounting" models that simulated the decision making process through time.

The same can probably be said of the preference ordering methodologies used in the Grand River Study. Impact matrices, used in this and a number of other studies reviewed above, appear to be indispensable tools in planning. But the Grand River study went beyond this, using voting algorithms and fuzzy-set analysis to analyze several alternative sets of preference data. These analyses were a valuable means of integrating and summarizing a large body of information, and appeared to do so in a reliable manner.

Final decisions however were the result of substantive discussions of goals, issues, costs and benefits during which judgement and compromise were of paramount importance.

Conclusions

- Unless explicitly required by established policy or administrative procedure, economic analysis are not extensively used in water resources planning in Ontario.
- The degree of sophistication of economic analysis tends to increase as the scope and complexity of the planning study increases and as studies become more directly linked to the follow-up implementation of measures.
- The calculation of project costs, the present value of costs and cost allocations, and a tabulation of all impact data (quantitative or qualitative) in a summary matrix are basic requirements for economic analysis in any studies that lead to recommendations on water resources management.
- Beyond the analyses mentioned in the preceding statement, additional economic analyses should only be undertaken if it is clear that they can make a substantive contribution to the decision making process in a study.
- A clear provincial policy governing the need for and use of economic analysis in water quality studies could enhance the value of such analysis in making resource allocation decisions.

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Institutional Considerations in Stream Management: The Need for a Negotiated Approach

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> When you have the answer to a problem
> all you have to organize is ignorance
>
> (M. McLuhan)

The principal problem in water management is not a technical nor a methodological one. Rather, it is the development of appropriate institutional arrangements that 'foster the comprehensive approach to regional water management' (Memon, 1970, 154). However, defining the problem has proved to be far easier than agreeing to its solution. This paper addresses the issue of institutional interaction in stream management and, following a brief outline of the problem, it forwards the case for a negotiated approach: not as a means to redefine the institutional arrangements for water management but, rather, as a strategy to organize the ignorance that prohibits existing arrangements from functioning successfully.

There is considerable fragmentation in Canadian natural resources legislation and administrative jurisdiction responsibilities. With the addition of the proposed Federal Environmental Protection Act there are now at least 30 pieces of legislation that affect water management in Ontario (Figure 1). Clearly, comprehensive management can involve a plethora of agencies, departments and boards, operating under a wide range of discrete but overlapping mandates.

The solution in Southern Ontario is supposed to be provided by the existence of Conservation Authorities. This approach is meant to give comprehensive management, especially over water control, through watershed jurisdiction and provide local leadership in the management of natural resources. However this arrangement often has been unable to facilitate successful plan implementation because considerable jurisdictional fragmentation remains and "control", in practice, rarely is vested in the Conservation Authorities themselves. For example, areas outside of Conservation Authority jurisdiction include:

FIGURE 1: MAJOR WATER-RELATED LEGISLATION IN ONTARIO

FEDERAL

- Atomic Energy Control Act
- Arctic Waters Pollution Prevention Act
- Boundary Waters Treaty Act
- Shipping Act
- Canada Water Act

Environmental Protection Act
Fisheries Act
Indian Act
International Rivers Improvement Act
Migratory Birds Convention Act
National Parks Act
Navigable Water Act
Oil and Gas Production and Conservation Act
Regional Development Incentives Act

PROVINCIAL
Beach Protection Act
Beds of Navigable Waters Act
Conservation Authorities Act
Consolidated Hearings Act
Drainage Act
Environmental Assessment Act
Environmental Protection Act
Game and Fish Act
Lakes and Rivers Improvement Act
Mining Act
Planning Act
Water Resources Act
Petroleum Act
Pits and Quarries Control Act
Pollution Abatement Incentives Act

Municipal responsibility for:	Waste treatment planning and development control local drainage
and	
Provincial responsibility for:	Forest management wildlife habitat management agricultural land drainage sewage treatment water supply solid waste disposal water quality fisheries habitat management aggregate management air quality parks

Further, while the Ministry of Natural Resources and the Ministry of Environment are the main provincial agencies involved with water management, a given issue may involve the Ministries of Agriculture and Food, Culture and Recreation, Housing and Municipal Affairs, Industry and Tourism, and Transportation and Communication, plus several municipalities and Regional governments. It is an understatement to point out that it is rare for any of these institutions to surrender an area of their mandate and responsibility to the exclusive jurisdiction of a Conservation Authority.

Thus, a problem remains with the excessive number of management agencies that exist and the overlapping nature of their mandates. Moreover, the financial, political and technical integration necessary to deliver management programs is often beyond the capacity of individual Conservation Authorities. Hence, inter-agency co-operation has remained essential and has been manifest in such instances as the Thames, the Grand and the South Nations Rivers and between Ontario and Quebec on the Ottawa River (c.f. Mitchell and Gardner, 1983).

At issue here should not be the institutional arrangements themselves. Whereas those arrangements are by nature fragmented, multiple and over-lapping they are, concomitantly, also potentially flexible, inclusive and open to adjustment. The problem is not the reality of the arrangements themselves but, rather, how to deal with that reality. As Dorcey (1987, 2) has written,

> The problem is not the split in federal and provincial rights and responsibilities, nor the multiplicity of jurisdiction and interests, nor the complexity and uncertainty of science. Rather these are the realities and the problem is our poor skills in handling the interaction they necessitate.

Support for this view comes from the experience in the United States (Platt, 1987) which underscores the fact that refining and redefining the institutional arrangements is not the solution. Administrative reforms, in and of themselves, can do little to alter the successful attainment of effective management practice. What is needed, are improved interactive skills of management, new methods of practice and greater attention to the human resources in resources management.

The principal issue to be addressed is that of management of conflict resolution. In the words of Thompson (1987,9),

> Most people involved in water resources management will subscribe to the principle of multiple use or integrated use. However it is a very unusual situation in which conflicts between users do not arise. It is equally unusual to find effective mechanisms and decision making criteria for conflict resolution. Until such mechanisms and criteria are developed and used, good water resources management will be difficult if not impossible.

Of critical importance in this respect are the management skills and techniques needed to affect co-operation and agency interaction. These abilities become all the more problematic in light of the fact that the traditional "management sciences" have not shown a propensity for adaptation to renewable natural resources such as water (Thompson, 1987, 10).

The public policy literature does identify that government co-ordination is a function of power relations (either through control or influence) and of the relative

authority and dependency of agencies (e.g. Kernaghan and Kuper, 1983). Thus, in essence, the problem in water management becomes one of determining the "how" and the "who" of government interaction (Cardy and Gregory, 1987). In this respect, the determination of policy objectives and plan implementation are offset by concerns for:

(1) inter-agency co-operation
(2) leadership
(3) the policy development process, and
(4) the role of the water manager.

The crux here is the fact that water development decisions have political as well as economic criteria to be met. Those political criteria tend to be imprecise. This fact is clearly underscored in Don Tate's discussion of water pricing and the political dilemmas posed by that issue. Moreover, as Mike Fortin's paper demonstrates, it is becoming increasingly apparent that even the economic criteria for water resources are steadily less and less black and white in nature as assessment decisions attempt to become more inclusive and realistic in their evaluations. Hence, the best that can be achieved is some acceptable level of *consensus* as to a solution. The corollary is that it is unlikely that any one process can ever attempt to deal with all of the issues, the limits to comprehensiveness being determined by the interrelationship of the inherent biases of the planning system and the relative power and influence of the various stakeholders.

These relationships are reflected in existing planning approaches. Typically, problems are defined in ways which correspond to known, desired solutions. Power and vested interest in conflicts are not given up in favour of a brokerage role and outside groups and stakeholders are often excluded from participation in the process, especially in the problem definition phase. As a result, regulations are stressed as a means of control and not accountability, decision making becomes inflexible and initiative and innovations are discouraged. What is needed is not more control but *better* control.

Environmental decision making in Canada is a bargaining process. However, all too often, bargaining is implicit to the decision process and explicit attention to negotiation is not present. This results in administrative discretion and selective consultation with discrete client groups as the norm, with issues being narrowly defined to reflect the known constituent interest despite their likely incompatibility with the concerns of other actors and the potential for conflict that accompanies this approach. In contrast, explicit attention to bargaining recognizes that the conditions that enable the resolution of conflict and the accommodation of interests are determined by the political culture of the decision system. Two aspects are crucial:

(1) the place and importance of negotiation in decision making processes, and
(2) the extent and role of public participation.

In this respect, it is important that bargaining be an explicit process of negotiation between stakeholders who have access to that process. That does not mean, however, that negotiation has to be an open process in a public forum. Indeed, many successful negotiations are conducted in private on an informal basis, whereas many public forums have failed due to the public posturing of participants. Clearly,

the distinction is not the visibility of the process but the explicitness with which the transactional nature of negotiation is recognized within that process.

In water resources management the reality of the institutional arrangements dictates that compatibility, and not integration, should be the goal of decision processes. What is needed to affect this goal are:

(1) real and regular consultation

(2) a common data base

(3) action plans involving multiple stakeholders, and

(4) a variety of flexible mechanisms.

The main obstacle to the effective implementation of these components is the paternalism endemic to government agencies. Thinking like DAD, the Decide-Announce-Defend approach to water planning, is often inherent in the institutionalized approach to consultation of management agencies. They possess the knowledge, the technical expertise, the skills and, above all, they mandate to act in the public interest. Consultation exists only as a vehicle to inform, to build support for preferred options, to add more winners to the win/lose equation of planning decisions. And, just like DAD, these same agencies also are under pressure that tends to further narrow viewpoints, stress internal agency goals and promote the exigence of intra-agency politics. The TAWMS study discussed by Lloyd Logan represents a recent illustration of this approach to the resolution of the water management problems of the Humber River basin.

To break away from this mold, the emphasis must be placed on the process for negotiation and accommodation within planning rather than the substantive differences between the stakeholders. The key to this transition is the acceptance of the concept that conflict is not inherently bad, or what Gerald Cormick of the Mediation Institute would refer to as the "Lipton" principle, 'you don't know the strength of the tea bag until it's in hot water'.

Having acknowledged that conflict is not inherently bad, the aim of the decision process becomes one of dispute resolution rather than conflict elimination. The process is used to expand the problem, to help establish compromise, to accommodate interests and to find areas of agreement that can be used to build consensus. This is the process of negotiation. Negotiation is explicit bargaining. Negotiation brings with it commitment from "the other side". Often the results of a negotiated planning process may not appear to be that different to a process without negotiation. The difference is commitment. Commitment from all parties to the process, who have "bought in" to the plan, its implementation and the planning process itself: often the process is the most important product.

The goal of a negotiated approach is to reach a mutually acceptable, jointly derived solution. Negotiation itself,

(1) facilitates better problem identification

(2) empowers a full range of stakeholders

(3) makes explicit and visible competing and conflicting values, and

(4) aids in the implementation of solutions.

It does this by utilizing a wide variety of strategies, the key being the employment of techniques that are appropriate to the given situation. What worked for the Grand River basin in the GRIC studies outlined by Tony Smith can not be automatically copied and replicated in other basins in Ontario. Individual circumstances, conflict histories and regional geographies dictate that normative models for a negotiated approach are optimistic at best and misleading at worst. One of the principal difficulties in negotiation is this factor: the large variability in strategies that can be used and the abscene of any real "paint-by-number" models or directives for successful negotiation. The literature does, however, offer some guidelines and principles that all negotiating strategies embody. For example, one important tenet is that of not

FIGURE 2: THE BASIS OF PRINCIPLED BARGAINING

PROBLEM *Positional Bargaining: Which Game Should You Play?*		SOLUTION *Change the Game- Negotiate on the Merits*
SOFT	**HARD**	**PRINCIPLED**
Participants are friends	Participants are adversaries	Participants are problem solvers
The goal is agreement	The goal is victory	The goal is a wise outcome reached efficiently and amicably
Make concessions to cultivate the relationship	Demand concessions as a condition of the relationship	Separate the people from the problem
Be soft on the people and the problem	Be hard on the problem and the people	Be soft on the people, hard on the problem
Trust others	Distrust others	Proceed independent of trust
Change your position easily	Dig in to your position	Focus on interests, not positions
Make offers	Make threats	Explore interests
Disclose your bottom line	Mislead as to your bottom line	Avoid having a bottom line
Accept one-sided losses to reach agreement	Demand one-sided gains as the price of agreement	Invent options for mutual gain
Search for the single answer: the one they will accept	Search for the single answer: the one you will accept	Develop multiple options to choose from; decide later
Insist on agreement	Insist on your position	Insist on objective criteria
Try to avoid a contest of will	Try to win a contest of will	Try to reach a result based on standards independent of will
Yield to pressure	Apply pressure	Reason and be open to reasons; yield to principle, not pressure

After Fisher and Ury, 1980, 13

bargaining over positions but, rather, to negotiate the merits of an issue: the basis of principled bargaining (Figure 2).

In Ontario, the negotiated approach to decision making presents an effective strategy to deal with the reality of the need for institutional co-operation is stream management. A negotiated approach would entail continued dialogue, such as that being fostered by the CWRA. It would involve also a commitment of trust in all stakeholders, a recognition of the legitimacy of conflicting views and the willingness of individuals to facilitate consensus.

These factors in themselves are not new but what is distinctive about a negotiated approach is a formal acknowledgement of the need to emphasize the *process* by which compatibility and co-operation can be facilitated. Moreover, a negotiated approach operates within the existing institutional structure and fosters implementation of new, compatible initiatives through existing programs.

Yes, the institutional arrangements for water management in Ontario are fragmented and complicated. Yes, the issues are complex and wrought with conflicts. But no, it is not necessary to ponder a vast over-haul of the decision system nor invest large amounts of time and money in elaborate, schematic flow charts that elegantly outline the "correct" cybernetics for water management. A negotiated approach presents a viable operating strategy for accommodation such that inter-agency co-operation ceases to be either a problem or a necessity but becomes instead a valued strength of Ontario's water management.

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Stream Management in the Grand River Basin

Tony Smith, Grand River Conservation Authority

Introduction

The main investigation period of the Grand River Basin Water Management Study extended from 1977 to 1981. Its purpose was to define the water management problems confronting the Grand River Basin and to develop a viable set of alternative water management plans. These plans are designed to meet the following water management objectives:

1) reduce flood damages;
2) provide adequate water supply;
3) maintain adequate water quality.

The study provides a comprehensive framework to aid elected representatives, officials and citizens in resolving water management problems. The framework is flexible enough to accommodate changing water management priorities and needs. It provides a means by which new projects and other plans can be evaluated. This paper outlines the formation, evaluation and selection of the preferred plan. It also reviews the progress made in implementing the plan in the last five years since the study was completed.

Background

The Grand River Basin (Fig. 1) is located in the southern part of the Province of Ontario, Canada. It has a drainage area of 6700 km^2, and extends 300 km. from the Village of Dundalk in the north to Lake Erie in the south. Land use is varied with agricultural and rural land uses dominant in the northern and southern portions and urban and industrial land uses common in the central portion. Five cities within this central portion; Kitchener, Waterloo, Cambridge, Guelph and Brantford place high demands and stresses on surface and ground water resources.

The Problem

The main basin water management problems are flooding, water shortages, and water quality. Problems are largely confined to the urban and industrial middle third of the basin. The problems are historic in nature. Since the early 1800's when Europeans first settled here, the Grand River and its tributary streams have been the nucleus for both urban and rural development. At each urban centre, small mill dams were built to provide water power and the rivers were used to provide water supply and convenient disposal of domestic and industrial wastes.

Despite the construction of three multi-purpose reservoirs, the construction of several dykes and an active program of flood plain zoning, average annual damages still amount to over $400,000 per year.

These damages will probably increase since recent studies (W.T. Dickinson) have indicated that the probability of flooding at Cambridge in the central portion of the basin has increased since the early 1900's.

Oxygen-demanding organic wastewater discharges from six sewage treatment plants deplete the oxygen resources of the water course. At the same time, nutrient inputs from the sewage treatment plants and rural diffuse sources stimulate, in certain sections of the river, the growth of aquatic plants and algae which consume large amounts of oxygen during the night. During the critical summer period, this combined effect has led to severe oxygen depletions and excessive aquatic plant growth in the Speed River below the City of Guelph (20 km. affected) and on the Grand River from Kitchener to Cambridge (40 km. affected).

Water shortage problems in the basin principally relate to the growth in the Kitchener-Waterloo-Cambridge area. The existing ground water supply will have to be supplemented by additional surface and ground water supplies in the next five years. The area already has had to impose restrictions on water use. The existing use of water from the river by such downstream communities as Brantford and its probable use by the Kitchener-Waterloo-Cambridge areas will require careful water quality control, particularly with respect to toxic contaminants.

Issues

Allied with these problems were several controversial issues, primarily dealing with past or recommended solutions to the above problems.

One issue was the question of constructing another multi-purpose reservoir, the Montrose Reservoir (Fig. 4), in a largely rural area. Several ground water interference problems have already been encountered in the areas of high abstraction near Kitchener and Waterloo.

An ever-recurring issue was the preference of some urban and rural citizens for a Great Lakes pipeline to supply the needs of Kitchener-Waterloo and Cambridge over alternate ground water or surface water supplies.

The Basin Study

The study was started in 1977, lasted four and a half years and cost $1.6 million dollars.

The study was directed by a steering and co-ordinating committee called the Grand River Implementation Committee, made up of members from five participating ministries and agencies (Provincial Ministries of Agriculture and Food, Environment, Municipal Affairs and Housing, Natural Resources, Treasury and Economics and the Grand River Conservation Authority). The technical work of the basin study was carried out by five sub-committees and several advisory groups (Fig. 2). Two important advisory groups were the Public Involvement Program Advisory Group and the four regional Public Construction Working Groups, both of whom provided advice to the steering committee (Public Consultation Working Group Report, 1982). Basin residents with diverse backgrounds and interests served on these groups. The Public Consultation Working Groups played a major role in evaluating and selecting a management plan.

Development of Water Management Alternatives

Initially, the formation of various water management alternatives began by identifying a range of proposed structural and non-structural water resource projects which could contribute to achieving the basin study's objectives to reduce flood damages and ensure adequate water supplies and maintain adequate water quality.

The projects were combined to form water management plans which were evaluated using simulation models to determine effects such as flood damage reduction and dissolved oxygen improvement. The plans were also evaluated economically by two models, a linear program model, and an interactive decision-making model. The latter model was a cost benefit model where the user stated the various plan descriptions, and water quality constraints and the model produced costs, benefits and staging of projects. The plans were designed to incorporate growth projections until the year 2031. Population is expected to grow from 600,000 in 1980 to between 700,000 and 900,000 in 2001 and between 900,000 and 1,600,000 by the year 2031. To assess the plans sensitivity to population estimates, each plan was evaluated for three population projections: low, medium and high.

With the aid of these models, twenty-six alternative water management plans were produced and evaluated.

Preliminary Plan Evaluation

A comparison of damage reduction, resulting from a combination of reservoirs, reservoir operation, dykes and channelization was made with the use of the HEC-5 simulation model (U.S. Army Corps of Engineers, 1975) and the Conservation Authorities Branch FLOOD 2 Model (1975 modified).

It was concluded that the flood damages can be reduced 97% by channelization and dyking and 60% by the Montrose Reservoir, the most efficient of the reservoirs investigated.

Water quality was modelled using a one-dimension continuous simulation water quality model which was developed for the study and is capable of long-term simulations (up to twenty years) on a two-hour time step. For the central area in 14 reaches, the model simulated a twenty year record of dissolved oxygen levels, BOD, NOD, NO_2, NO_3, unionized ammonia, SS, Total P, and the growth and decay of aquatic plants.

After examining various sewage treatment and flow options, the study concluded that the highest dissolved oxygen levels in the central portion of the basin could be achieved by:

a) adding nitrification and sand filters at the Kitchener and Waterloo treatment plants;

b) improving phosphorus removal at the Guelph sewage treatment plant to effluent phosphorus concentrations of approximately 0.1 mg/1;

c) increasing the minimum summer flows by 3.4 m3/sec cfs. through the use of the Montrose Reservoir.

With the above treatments, the average year would almost meet the dissolved oxygen objective of 4 mg/l, while during the worst year (1 to 20) violations would still occur but less often. To reduce the violations further would require a massive reduction in phosphorus input, both from the sewage treatment plants and upstream rural non-point sources.

The study findings indicated that existing ground water supplies in the Kitchener-Waterloo area will have to be supplemented by recharge from river sources or by lake sources via a 77 km. pipeline from Lake Erie. However, the use of water conservation in curtailing demand can delay the need for various water supply projects 5 to 10 years, depending upon the effectiveness of the conservation methods.

Screening of Water Management Plans

In order to reduce the twenty-six plans to a manageable number for detailed analysis, a preliminary screening of the water management plans was carried out. This screening process consisted of a series of evaluations which eliminated less optional plans from further consideration. The preliminary screening was carried out by: (1) comparing how satisfactorily each plan fulfilled the objectives; (2) comparing plan costs; and (3) comparing environmental and social impacts. The evaluation was done by giving a grading of very good, good, fair and poor to each plan in relation to objectives, costs and impacts.

Each plan's effectiveness in achieving the basin study objectives was determined by using the following measures of benefits. The reduction in average annual flood damages was used to measure each plan's flood control benefits and the principle of consumer surplus was used to estimate the economic benefits of water supply expansions. A water quality index based on dissolved oxygen levels developed specifically for the basin study, was used to assess water quality benefits in the preliminary screening. The environmental and social impacts for each plan were graded using the results of a specially designed questionnaire completed by technical members of the study and analyzed using a multi-criteria method.

Plan Selection

After the twenty-six alternative plans were evaluated by the screening process, the plans were reduced by the following three-stage process;

1) selection of plans from a Plan Evaluation Matrix, using a multi-criteria method;
2) selection of plans by the Basin Technical Study Team using a voting analysis technique;
3) selection of plans by the Grand River Implementation Committee after evaluating the results of steps 1 and 2 and the recommendations from the public consultation working groups.

This process led to the selection of four main plans for detailed evaluations. Several options associated with three of the plans were also evaluated.

Final Plans

Plan A embraces a "no reservoir" option using channelization and flood plain zoning to reduce flood damages, advanced sewage treatment to improve water quality and ground water recharge from the Grand River to augment water supply in the Kitchener-Waterloo-Cambridge area. Various water conservation methods are recommended to reduce demand and delay the need for structural solutions. An option of this is Plan A-4 which is the same as Plan A except that it includes the preservation of the Montrose Reservoir site either through zoning or gradual acquisition of the land at prevailing market prices.

Plan B is basically a reservoir plan where flood reduction is provided by channelization, flood plain zoning and the Montrose Reservoir, water quality is improved by advanced sewage treatment and improved summer flows from the Montrose Reservoir. Water supply is increased and demand decreased in the same fashion as Plan A.

Plan C considers various single purpose reservoir options to reduce flood damages. Water quality is improved and water supply increased as in Plan A.

Plan D is the same as Plan A except future water supply is provided by a Great Lakes pipeline to Lake Erie.

In summary, Plan A is the most economical plan and affects the rural community the least. Plan A-4 provides the most flexibility in that the Montrose site would be preserved until future risks and uncertainties are dispelled. Such uncertainties as the increase in flood flows, population projections and accuracy of simulation results.

Plan B2 is the most reliable plan since it gives additional flood protection, and increased water quality. However, it costs $31 million dollars more than Plan A and has higher environmental and social impacts on the rural area than does Plan A.

Plan D, while having a minimum long-term environmental and social impact, is the most expensive plan with pipeline operation costs of over $5 million per year.

Plan costs and benefits with additional advantages and disadvantages are compared in Table 1 and Figure 7.

Final Selection

The four plans and their related options were compared and evaluated by Technical members of the basin study team, water managers from the major municipalities in the basin, and the four Public Consultation Working Groups. These evaluations were considered by the Grand River Implementation Committee in their identification of the preferred plan.

Evaluation of Plans by Technical Group

The technical staff selected Plan A (no reservoir plan) and Plan B (reservoir plan) as the best plans, but preferred plan A4 (preservation of Montrose site) over all the others.

In contrast, the water mangers who are charged with the day-to-day responsibility of operating major flood control, water supply and sewage treatment services preferred plan B2 (reservoir & dykes) because it offered, in their opinion, a more reliable and secure water management system.

Evaluation of Plans by Public Group

The evaluation by representatives of the public was carried out by four public consultation working groups made up of citizens from different geographical areas of the basin. Three of the four working groups selected plan A1 and A2 as the preferred plans. The fourth group, representing the lower portion of the basin preferred plan B2, the Montrose Reservoir option, because of its greater ability to reduce flood flows, maintain higher summer flows and improve water quality.

The working groups tended to favour the plans with minimal social impacts. Two of the three public groups selecting plan A1 and A2 were opposed to plan A4 (preserve the Montrose Reservoir site).

Preferred Plan

After reviewing the results from the technical and public groups, the steering committee selected the most flexible of the four plans, plan A4 as the preferred option for water management in the Grand River basin.

The principle features of the proposed basin management plan are:

a) the use of channelization and dyking to reduce annual flood damages by 91%;

b) continuing development of ground water and further use of the Grand River to meet increasing water demands at Kitchener, Waterloo, Cambridge and Brantford;

c) advanced sewage treatment at Kitchener, Guelph and Waterloo over a period of years to improve water quality in the Grand and Speed rivers;

d) the protection of the Montrose reservoir site for possible future water management purposes by planning controls and if necessary, land acquisition on a market basis.

The selection of this plan was made because the $72 million cost of the plan is near that of the lowest cost final option, the environmental and social impacts are comparatively low, and flexibility to deal with future changes and uncertainties is enhanced.

It was recommended that the plan be implemented by existing government ministries, municipalities and the GRCA. Co-ordination would take place through the creation of a co-ordinating committee similar to the former Grand River Implementation Committee.

This plan was then presented to the government in April of 1982. The Cabinet Committee on Resources Development authorized the release of the report and requested a full review of the report by the affected municipalities.

Cabinet Submission

Municipal and provincial comments were incorporated into a slightly revised proposal and submitted to Cabinet in 1984. It was hoped that the plan would be endorsed by the cabinet and such an endorsement would provide the confidence needed by the various implementing agencies to go forward with an approved planning framework for water management. However, to date no announcement of formal support of the plan has ever been made by Cabinet. One can assume that tacit unofficial approval has been given since the major portions of the plan are now being implemented without formal endorsement.

Components are being carried out under existing programs within the normal funding allocations to the responsible ministers.

Current Implementation

At present, there is no one agency responsible for implementing all aspects of water management in the Grand River.

The authority to implement various aspects of the preferred plan is divided among several agencies as outlined in Table 2. Each agency involved in implementing the plan has differing priorities with respect to carrying out its mandate as well as varying water managment priorities. This is a direct result of the range of responsibilities

allocated to it through legislation and the overall funding available to carry out these responsibilities.

The steering committee (GRIC) as well as several of the public consultation working groups felt that this jungle of jurisdiction plus the lack of a co-ordinating body could impede the implementation of the plan. However, to date this has not occurred. Over seventeen of the twenty-two study recommendations have been acted upon in the last five years.

Dyking and channelization are being undertaken at Cambridge and Brantford. Over $12 million has been spent to date in construction of dykes at these two locations.

The Regional Municipality of Waterloo has recently completed a Master Water Supply Study. This study reviewed in further detail the Plan's recommended surface and ground water supply options. A class environmental assessment is currently being prepared for the recharging of the Mannheim aquifer by water from the Grand River. Water conservation has been continued in the region to reduce municipal water demands.

Advanced sewage treatment is planned to be installed at the Waterloo sewage treatment plant. The Guelph sewage treatment is being upgraded and reevaluated.

The Ministry of Agriculture and Food and the GRCA have formed a joint agricultural soil and water conservation programme to aid farmers in solving their erosion problems through the use of various soil conservation approaches.

The Strengths and Weaknesses of the Basin Study

The most important strength of the study has been its ability to get several government ministries and agencies to:

a) agree upon a common course of action;

b) co-operate in carrying out the various components of the plan.

The success in implementing portions of the plan has been due in large part to the studies' participants actively working to achieve the recommendations which are their ministries' or agencys' responsibility.

However, after five years, the implementation process is gradually loosing its impetus. This is largely due to personnel changes, shifts in organizational priorities and lack of familiarity with the original study.

This may be perfectly normal. After five to ten years, any watershed plan probably becomes obsolete and requires updating and modification to reflect changes in population, land use and technology.

Another strength of the Basin Study was the opportunity to use state of the art optimization and simulation models in an applied sense. Many of these models such as the water quality and hydrologic models can continue to be used in future to support more detailed analysis of various projects to be implemented.

For example, the water model has recently been used in assessing the impacts of water supply withdrawls from the Grand River for the recent Region of Waterloo Master Water Supply study.

While the opportunity to try new technologies is an advantage, it can also be distinct disadvantae when the modelers from the various agencies wish to try bigger and more complex models which may meet the needs of their agency's interest but may not meet the basin study needs for speedy and accurate answers.

A completed hydrologic continuous simulation (NWS) model was discarded for a more simple event model FLOOD 2 which more effectively determined the flood damage reduction of each plan. A linear program optimization model was simplified to a simple interactive operations model.

Another strength of the study was active use of the four regional public consultation working groups in evaluating the plans and selecting the final alternatives. The facilitated two way interaction and dialogue between the public and study personnel. The group also advised the steering committee directly in evaluating the various plans.

Summary

The Grand River Basin Study spend 4 years and $1.6 million in producing a water management plan. This plan will provide a framework to aid elected representatives, officials and citizens in resolving the major issues of water supply, water quality and flooding that occur in the watershed.

The study was completed in 1982 and reviews by municipal and provincial agencies were completed in 1984. While never formally endorsed, major portions of the plan have been implemented in the last five years.

FIGURE 1: LOCATION MAP OF THE GRAND RIVER BASIN

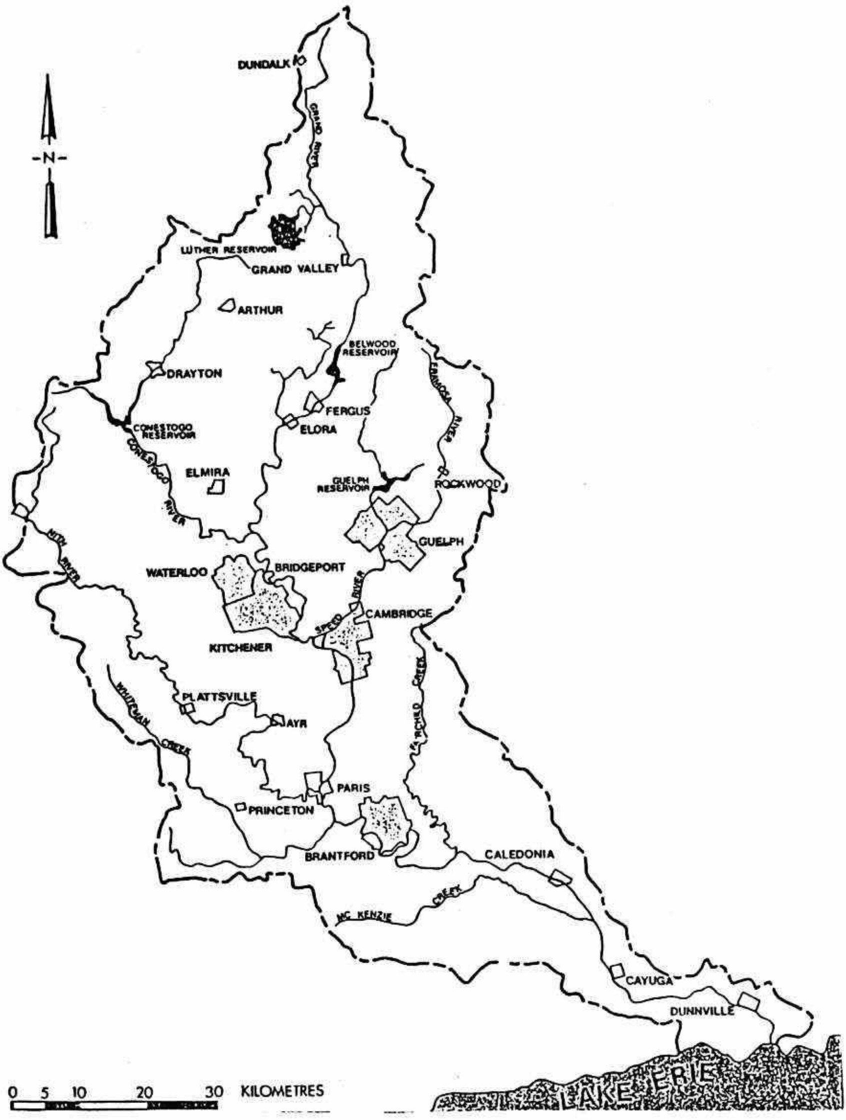

FIGURE 2: ORGANIZATION OF THE GRAND RIVER BASIN

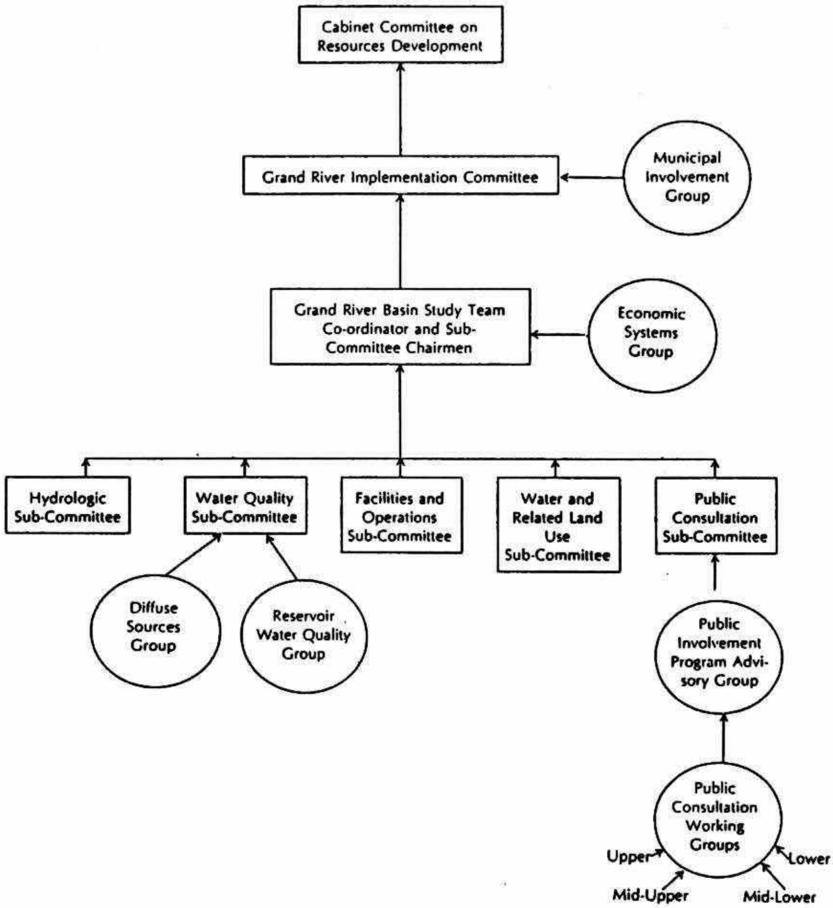

FIGURE 3: WATER MANAGEMENT PLAN A1

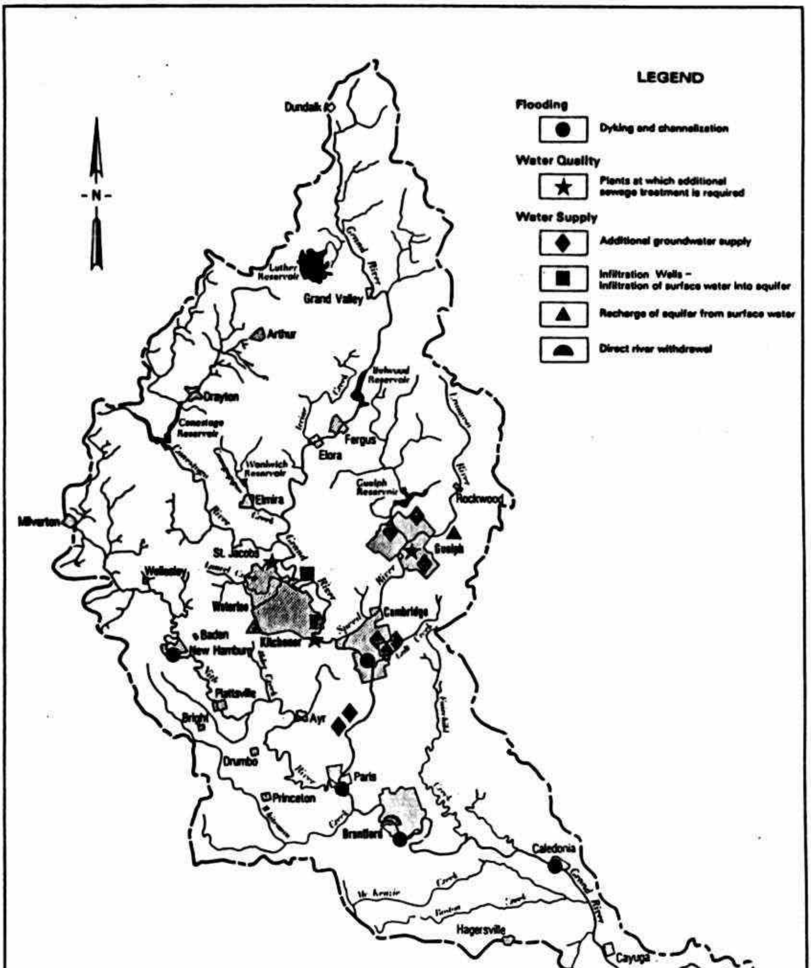

FIGURE 4: WATER MANAGEMENT PLAN B2

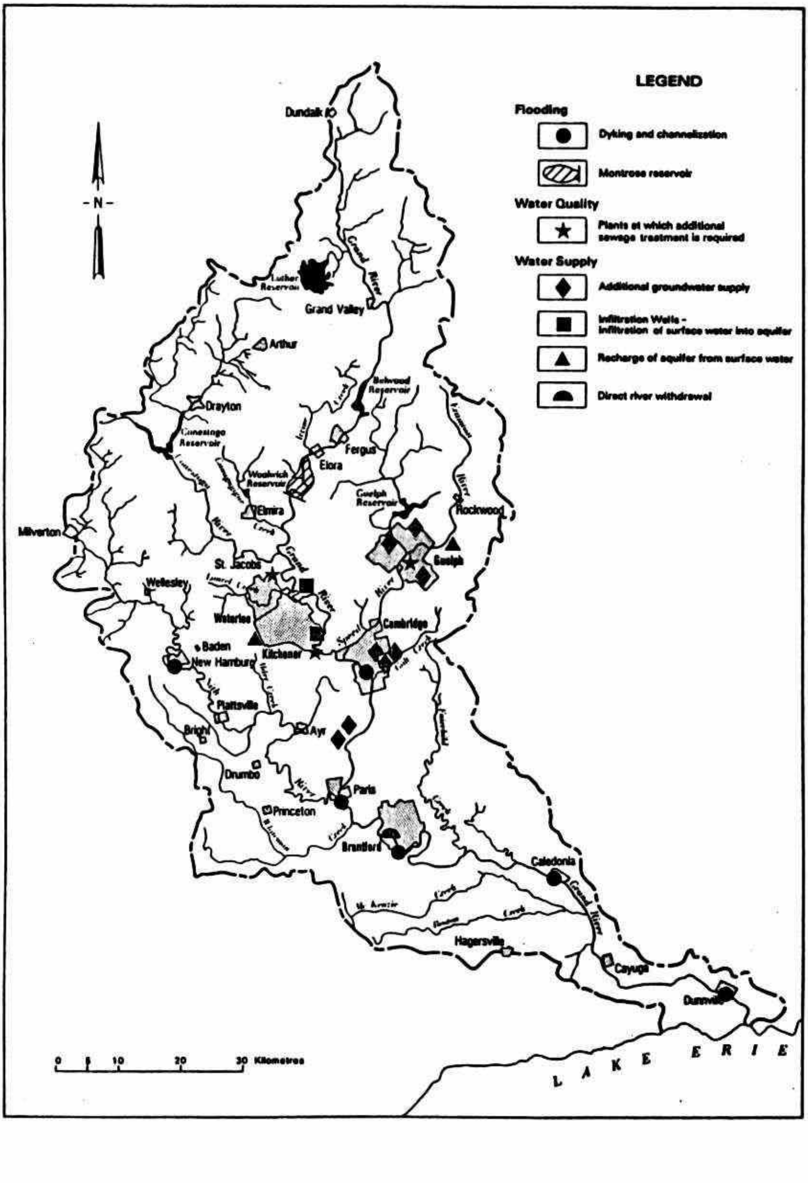

FIGURE 5: WATER MANAGEMENT PLAN C

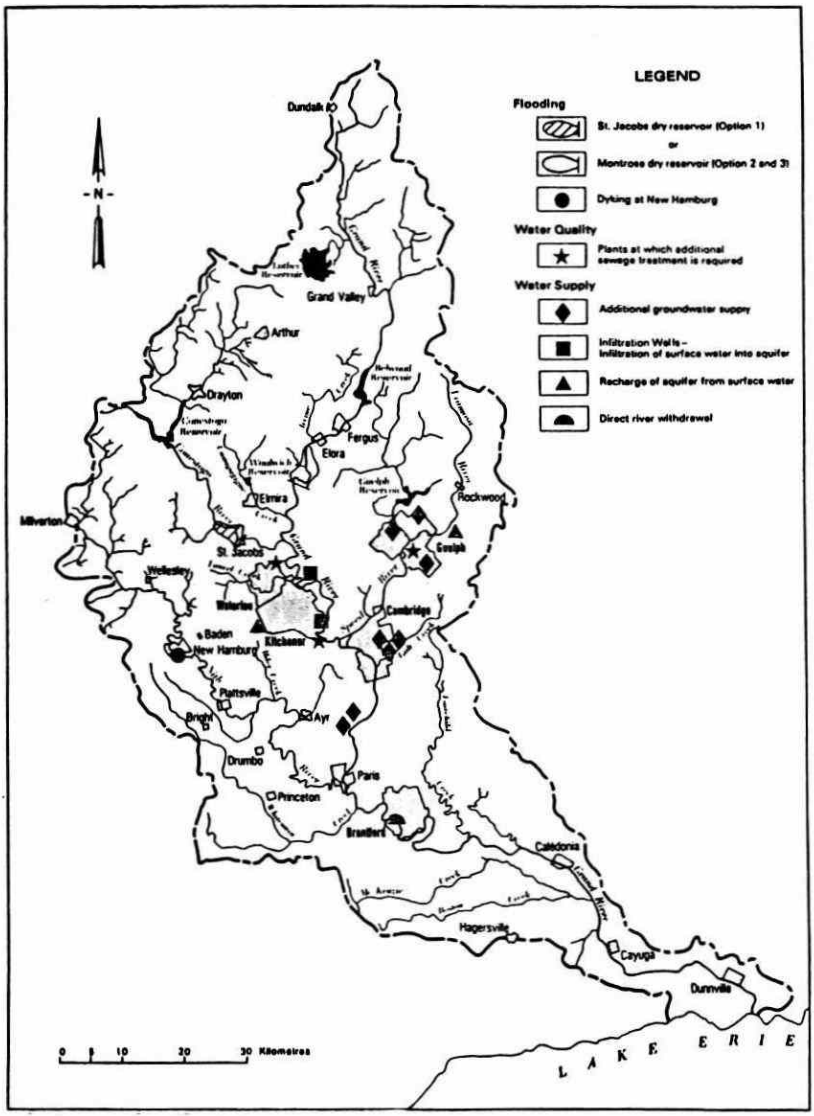

FIGURE 6: WATER MANAGEMENT PLAN D

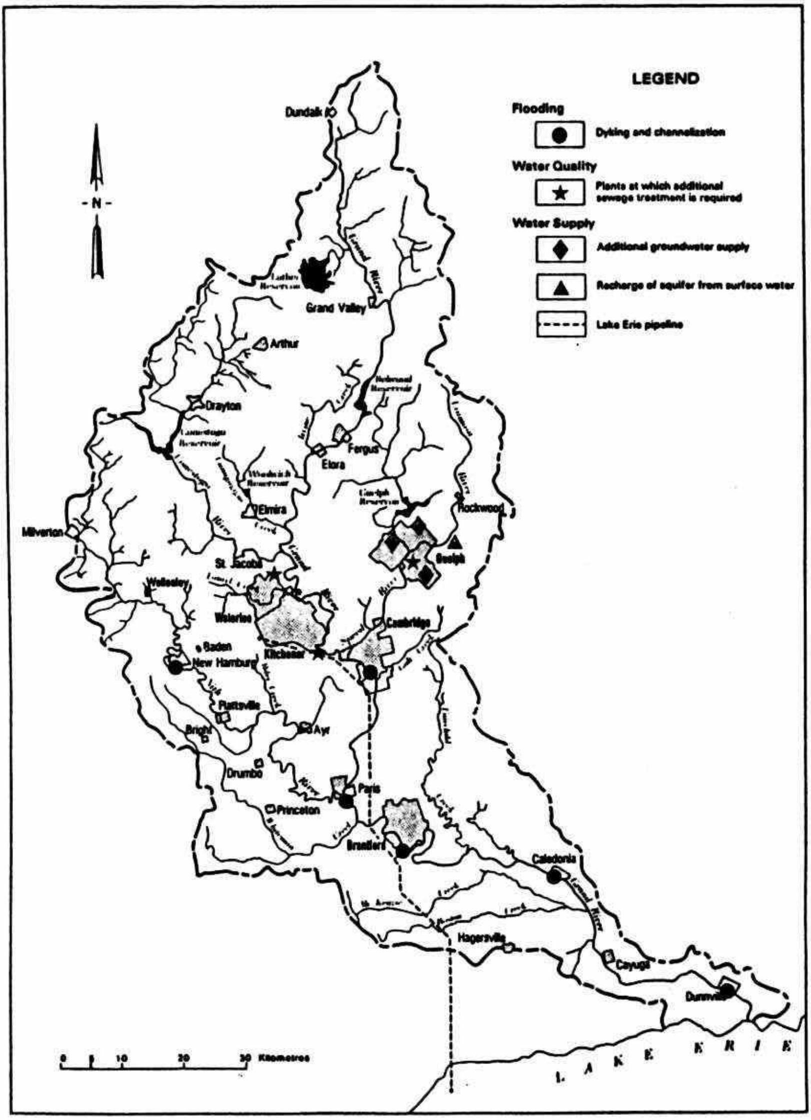

FIGURE 7: COMPARISON OF MAIN PLANS FOR A MEDIUM POPULATION PROJECTION

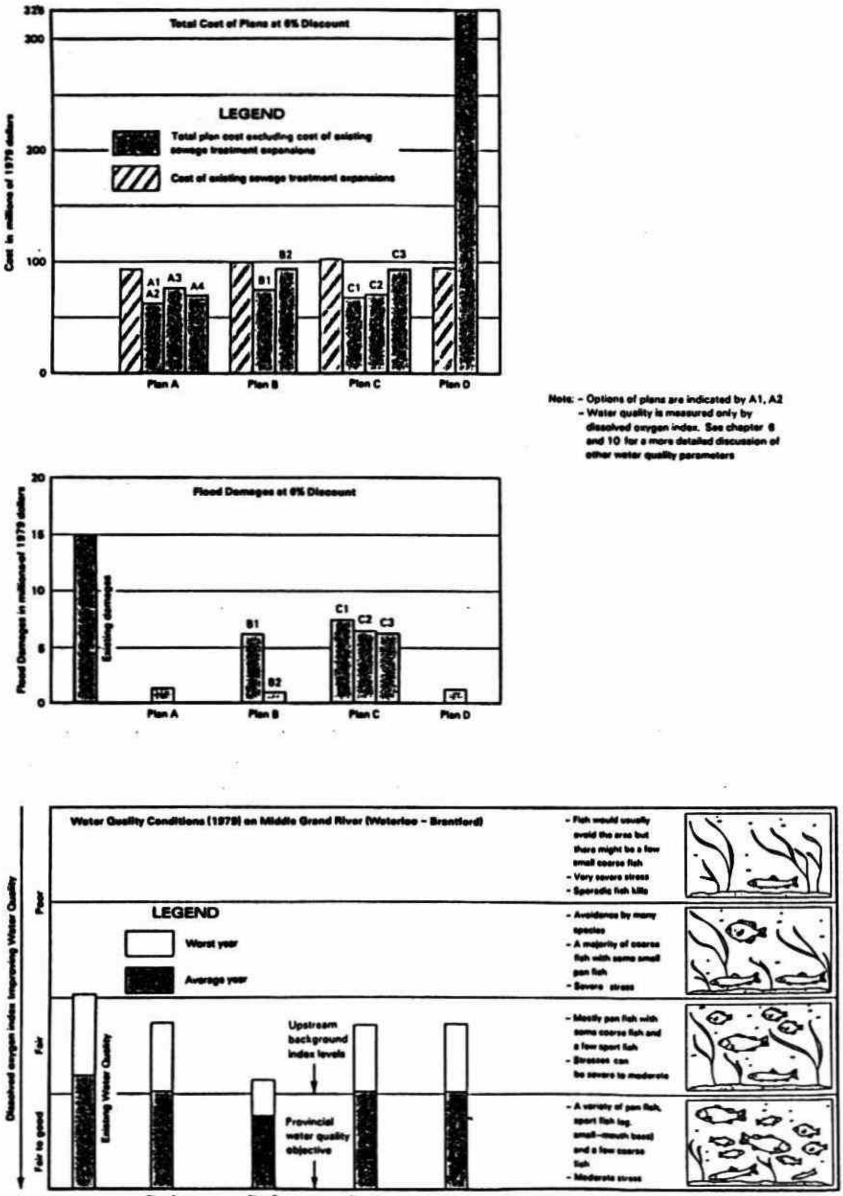

TABLE 1: COMPARISON OF MAIN PLANS - MEDIUM POPULATION PROJECTION

Plan	Costs Present value at 6%, millions of 1979 dollars	Benefits	Advantages	Disadvantages
Plan A1, A2 • Dyking and channelization at New Hamburg, Cambridge (Galt and Preston), Paris, Brantford, Caledonia and Dunnville • Advanced sewage treatment for Kitchener, Waterloo and Guelph • Local sources of water supply Plan A1 - new ground water supplies for Cambridge Plan A2 - new water supply to Cambridge via Mannheim recharge system	68* 66*	121 121	1. Lowest cost solution. 2. Minimal environmental and social impacts, localized to dyking and channelization sites. 3. Water quality on Grand and Speed rivers generally is improved, but does not meet MOE D.O. objective fully near Kitchener and Guelph. 4. Provides urban flood protection against floods greater than 100-year flood at sites with dyke protection (91% reduction in flood damages). 5. Meets water supply needs. 6. Socially most acceptable as reflected by Public Consultation Working Groups.	1. Lower water quality on Grand river (Waterloo to Paris) than B1, B2. 2. No additional flood protection for areas not provided with dykes. 3. Flood damage reduction provided only if dyke projects are carefully planned and co-ordinated.
Plan A3 • Same as A1 plus Everton reservoir on Speed river	84*	121	1. Flood protection and water supply same as A1. 2. Water quality on Speed river below Guelph is better than A1, but still does not meet MOE D.O. objective fully.	1-3. Same as A1. 4. Has detrimental impact on cold water fishery in reservoir site. 5. Reservoir increases A1 costs by $16 M.
Plan A4 • Same as A1 plus appropriate measures to be taken to preserve the Montrose reservoir site for possible future use	72* (Montrose lands disposed of in 2001) 83* (Reservoir constructed in 2001)	121 121	1. Water quality, flood protection and water supply same as A1. 2. Minimal environmental impacts (unless dam is constructed in the future). 3. Gradual social impacts during land acquisition. 4. Flexibility to handle future water quality uncertainties is increased. 5. Permits continued agricultural use of lands in reservoir acquisition area.	1-3. Same as A1. 4. Does not eliminate uncertainty about future land use. 5. No assurance that land-use planning can preserve the reservoir site except through provincially imposed regulations or purchase. 6. $4 M more costly than A1 if the reservoir is not built and $15 M more costly if the reservoir is built.
Plan B1 • Montrose dam • Advanced sewage treatment at Kitchener and Guelph • Local sources of water supply same as A1	74*	116	1. Water quality on Grand and Speed rivers is improved over Plan A, but still does not meet MOE D.O. objectives fully near Kitchener and Guelph. 2. Provides flood protection against a 10-year flood. 3. Provides additional flood protection for rural areas. 4. Meets water supply needs with greater flexibility for possible future needs. 5. Reservoir provides additional recreational opportunities.	1. Costs $6 M more than A1. 2. Has detrimental social and environmental impacts. 3. Provides less flood protection than A1. 4. Has considerable local opposition.

Table 1 (cont'd)

Plan B2 • Montrose dam • Dyking and channelization same as A1 • Advanced sewage treatment at Kitchener and Guelph • Local sources of water supply same as A1	97*	122	1. Same as B1. 2. Provides urban flood protection against floods greater than a 100-year flood (96% reduction in flood damages) as A1. 3. Reduces the risk of dyke failure by reducing flood peaks. 4. Provides added protection if future flood flows increase due to changing land-use practices. 5. Provides additional flood protection for rural areas. 6. Meets water supply needs with greater flexibility for possible future needs. 7. Reservoir provides additional recreational activities.	1. Costs $29 M more than A1. 2. Has detrimental social and environmental impacts. 3. Has considerable local opposition.
Plan C1 • St. Jacobs dry reservoir with dyking and channelization at New Hamburg • Advanced sewage treatment same as A1	70*	115	1. Less environmental impact than Montrose dam. 2. Provides urban flood protection against a 10-year flood and reduces flood damage by 50-49%. 3. Water quality on the Grand and Speed rivers improved, but does not meet MOE D.O. objective fully near Kitchener and Guelph. 4. Meets water supply needs. 5. $27 M less costly than B2.	1. Has detrimental social impact. 2. Provides less urban flood protection than A1, A2, B1 and B2. 3. $2 M more costly than A1.
Plan C2 • Montrose small dry reservoir, 24.7 million cubic metres (20,000 acre ft) with dyking and channelization at New Hamburg • Advanced sewage treatment same as A1 • Local sources of water supply same as A1	73*	116	1-4. Same as C1. 5. $24 M less costly than B2. 6. Reduces flood damages by 56-54%.	1-3. Same as C1. 4. $5 M more costly than A1.
Plan C3 • Montrose large dry reservoir, 77.7 million cubic metres (63,000 acre ft) with dyking and channelization at New Hamburg • Advanced sewage treatment same as A1 • Local sources of water supply same as A1	87*	116	1-4. Same as C1. 5. $10 M less costly than B2. 6. Reduces flood damages by 57-56%.	1-3. Same as C1. 4. $19 M more costly than A1.
Plan D • Pipeline from Lake Erie • Dyking and channelization same as A1 • Advanced sewage treatment same as A1	331**	80	1. A secure source of water supply (water supply needs are met). 2. Provides urban flood protection against floods greater than a 100-year flood at sites with dyke protection (91% reduction in flood damages). 3. Water quality on the Grand and Speed rivers improved, but does not meet MOE D.O. objective fully near Kitchener and Guelph. 4. Services cities along the Grand river from one source with capacity limited only by design and cost considerations.	1. Highest cost plan. 2. Large short-term environmental impact along route. 3. High energy use for pumping - over $5 M annual operation costs. 4. Flood damage reduction provided only if dyke projects are carefully planned and co-ordinated.

TABLE 2: PRINCIPAL AGENCIES RESPONSIBLE FOR THE IMPLEMENTATION OF WATER MANAGEMENT ALTERNATIVES

Plan Component	Pertinent Statute/ Program	Administering Agency	Implementing Agency	Financial Arrangements
FLOOD DAMAGE REDUCTION				
Floodplain Regulation	Conservation Authorities Act Planning Act Canada Water Act - Flood Damage Reduction Program	MNR MAH Environment Canada and MNR	GRCA Municipalities GRCA	Grant for administering 55%. MAH planning study grants. Floodplain mapping 90%.
Dams and Reservoirs	Conservation Authorities Act Lakes and Rivers Improvement Act Municipal Act	MNR MNR MAH	GRCA	Provincial grant 55%.
Dyking and Channelization	Conservation Authorities Act Municipal Act	MNR MAH	GRCA Municipalities	Provincial grant 55%.
Floodplain Acquisition	Conservation Authorities Act Municipal Act	MNR MAH	GRCA Municipalities	Provincial grant 55%.
Flood Proofing	Conservation Authorities Act	MNR	GRCA	100% of cost assumed by property owner.
Flood Forecasting and Warning	Conservation Authorities Act	MNR	GRCA	Provincial grant 55%.
Rural Land Use Practices	The Drainage Act The Tile Drainage Act The Planning Act	OMAF OMAF MAH	OMAF OMAF Municipalities	Provincial grant 33-1/3%. Secured loans not to exceed 75% of total cost of drainage works. MAH planning study grants.
WATER QUALITY				
Design, Construction and Maintenance of STPs	Ontario Water Resources Act Municipal Act Public Utilities Act Regional Municipality of Waterloo Act	MOE MAH MAH MAH	MOE Municipalities Municipalities Regional Municipality of Waterloo	Provincial grant available to municipalities up to 15% of net capital cost.

TABLE 2: (Cont'd)

Monitoring and Controlling Contaminants	Ontario Water Resources Act	MOE	MOE	
	Environmental Protection Act	MOE	MOE	
	Pesticides Act	MOE	MOE	
	Fisheries Act (Canada)	MNR	MNR	
	Municipal Act	MAH	Municipalities	
	Regional Municipality of Waterloo Act	MAH	Regional Municipality of Waterloo	
Flow Regulation	Conservation Authorities Act	MNR	GRCA	
Rural Land Use Practices	Farm Productivity Incentive Program	OMAF	OMAF	Provincial grant 40% up to $3,000 per farmer.
	The Planning Act	MAH		
WATER SUPPLY				
Design, Construction and Maintenance of Water Works	Ontario Water Resources Act	MOE	MOE	Provincial grant available to municipalities up to 15%* of net capital costs.
	Public Utilities Act	MAH	Municipalities	
	Regional Municipality of Waterloo Act	MAH	Regional Municipality of Waterloo	
	Local Improvement Act	MAH	Municipalities	
Water Abstraction	Ontario Water Resources Act	MOE	MOE	
	Pits and Quarries Act	MNR	MNR	
Flow Regulation	Conservation Authorities Act	MNR	GRCA	

* Small communities may receive up to 75% of net capital cost.

Hydro-electric Generation on Multi-purpose Watersheds*

C.W. Stevens, Ontario Hydro

Summary
In recent years, power producers have been restricted in their uses of rivers and reservoirs by an increase in water-related activities throughout society. By careful consideration of known constraints and the application of current hydrologic technology, operators of water controlling systems can minimize the impacts of their operations on other users, usually at little or no cost to themselves. Power producers must accept this fact or we risk legislative restrictions on our activities.

Background

For years, many owners and operators of hydro-electric power generation facilities have appeared to operate in the belief that the rivers upon which they are situated were put in place by the Creator purely for their sole use. However, if we go back in time to the period when the ground rules for hydro-electric power generation were being established by governments, it is apparent that the regulatory agencies did not always accept the power companies view. Two examples will demonstrate this.

Article VIII of the Boundary Waters Treaty of 1909 between Great Britain (Canada) and the United States of America states:

> "The following order of precedence shall be observed among the various uses enumerated hereinafter for these waters, and no use shall be permitted which tends materially to conflict with or restrain any other use which is given preference over it in this order or precedence:

(1) Uses for domestic and sanitary purposes;

(2) Uses for navigation, including the service of canals for the purpose of navigation;

(3) Uses for power and for irrigation purposes."

The power interests were clearly placed no higher than third on this list when this treaty was signed.

Article 2 of the Convention and Protocol of 1925 concerning operation of the Lake of the Woods provides for:

> "... most advantageous use of the waters thereof and of the waters flowing into and from the lake on each side of the boundary between the two countries for domestic and sanitary purposes, for navigation purposes, for fishing purposes, and for power, irrigation and reclamation purposes."

* previously presented to Canadian Electrical Associations, March 1985.

Here the power interests fall to fourth position on the list.

These examples illustrate the attitudes of the regulatory agencies when the documents were prepared. In some cases these attitudes have been modified somewhat to fit the circumstances of particular projects. These special circumstances are detailed in licenses issued for the project.

The constraints implicit in these and similar documents have become an economic fact of life for the owners and operators of hydro-electric generating facilities in recent years. In the case of Ontario, while certain rivers were originally earmarked for power development, there are no river systems that can be considered as strictly power rivers in the province today. Some of the constraints affecting Ontario Hydro operations are: flood control, low flow augmentation (or pollution dilution), navigation (both commercial and recreational), fishing (commercial and recreational), cottaging, tourism, other electric generating facilities, fur production, fish production, wild rice production, and native interests under various treaties.

In order to operate successfully in this environment, there must be a trade-off struck between power generation on one hand and the other interests on the other. Power can easily be quantified in economic terms. However, the dollar value of looking at a waterfall or canoeing a river is an intangible. In addition, if the value of fish netted by commercial fisherman on a lake can be determined, the public is often unwilling to accept that $50 of the fish equals $50 of electricity.

Allocation Of Water

Ideally the adjudication between the various users of water would be made in the political arena. However, in the absence of political guidence, these decisions fall, by default, to the operators of regulation structures and generating facilities throughout the watersheds.

The process used in Ontario Hydro to get out of this dilemma is ALLOCATION. This "allocation process" can best be described as the setting of priorities and the making of decisions with the knowledge that some users may be benefited and others may be harmed. The process of allocation implicitly acknowledges the fact that while, on rivers controlled by the Corporation, water is primarily used as a fuel, fundamental consideration must be given to the rights and needs of others.

Principles of Allocation

Water, with all its random quantities, is a gift of nature, which man uses in many ways to satisfy society's needs, and which must also satisfy nature's needs. As operator of the regulatory system, we must decide which other users get some of this resource and how much they will get. Since the value of many of the non-power uses cannot be realistically determined, these decisions are often subjective.

At this time, several guidelines exist which, although they do not remove this subjectivity, do serve to reduce the uncertainty in the decision making process. These guidelines vary from fixed legal requirements (incorporated in leases, legislation and documentary rights applicable to our operations) to inventories of information on other users, environmental concerns and matters of public safety.

Typical examples of these guidelines are:

Documentary Rights

- International Treaties
- Interprovincial Agreements
- Acts
  - Federal
  - Provincial
- Orders of Approval
- Licenses and Leases
- Flood Easements

Legal Requirements

- Maximum/Minimum Levels
- Flow Restrictions
  - Magnitude
  - Rate-of-Change

Public Safety

- Integrity of Control Works in
  - Structural Safety
  - Flow Capacity
- Downstream Impacts of Flow Changes
  - Flooding
  - Low Flows
  - Potentially Dangerous Situations

Other Uses of Water

- Environmental
  - Fish Spawn
  - Wildlife
    - Birds
    - Muskrats
  - Erosion
  - Debris
  - Ice
- Water Supplies
  - Industry
  - Municipalities
  - Recreation
    - Cottages
    - Boating
  - Transportation

Mississagi River

As an example of the various constraints affecting the allocation procedure, con sider the Mississagi River. The Mississagi, flowing into Lake Huron's North Channel near Blind River, Ontario, drains 9 300 km^2 of the South Slope of the Canadian Shield. Flows at the mouth have varied from 1 040 m^3/sec (May 7, 1928) to 2.1 m^3/sec (November 4, 1963).

Ontario Hydro operates one main storage reservoir (Rocky Island Lake) controlling 25 percent of the drainage area and four generating stations (Red Rock Falls, G.W. Rayner, Wells and Aubrey Falls) along the river with a total installed capacity of 500 MW. This system is generally run in a peaking mode.

A brief resume of constraints on the Mississagi River includes:

Documentary Rights

Rocky Island	License of Occupation 7198
	Navigable Waters Protection Act
Aubrey Falls GS	Water Power Lease Agreement No. 94
	Navigable Waters Protection Act
Rayner-Wells GS	Water Power Lease Agreement No.35
	Water Power Lease Agreement No.100
	Navigable Waters Protection Act
Red Rock Falls	Water Power Lease Agreement No.63
	Navigable Waters Protection Act

Legal Requirements

Rocky Island	(a) Maximum Level of 409.96 m CGD
	(b) Payment for Flooding Rights - $1,225.00/Year*
	(c) Adequate flow and level records

to describe the operation.

Aubrey Falls GS	(a) Maximum Level of 396.24 M CGD
	(b) Scenic Flow Over Aubrey Falls GS During Summer Months
	(c) Payment of Water rental - $96,789.00/Year*
	(d) Provision of Flow Records to Department of Public Works (DPW)
	(e) Adequate flow and level records to describe the operation.
Rayner-Wells GS	(a) Maximum Level of 275.85 M CGD
	(b) Payment of Water Rentals - $262,356.00/Year*
	(c) Provision of Flow, Level, to DPW
	(d) Adequate flow and level records to describe the operation
Red Rock Falls GS	
	(a) Maximum Level of 210.31 M CGD
	(b) Payment of Water Rentals - $140,991.00/Year*
	(c) Adequate flow and level records to describe the operation.

* 1982 Figures

Public Safety

Rocky Island Lake	Flood Storage
	Headwater and Tailwater Warning Signs
Aubrey Falls GS	Flood Storage
	Headwater and Tailwater Warning Signs
	Ice Control
Rayner-Wells GS	Flood Storage
	Headwater and Tailwater Warning Signs

Red Rock Falls GS	Flood Storage Headwater and Tailwater Warning Signs

Warning signs are also posted at public access points downstream from Aubrey Falls GS to Red Rock Falls GS indicating that river flows and levels can change suddenly and without warning.

Flood control of Iron Bridge through the cumulative effect of upstream storage.

Environmental Concerns

Rocky Island Lake	Trash Booms
Aubrey Falls GS	Trash Booms
Rayner-Wells GS	Trash Booms
Red Rock Falls GS	Trash Booms Pickerel Spawn Erosion Control Lampricide

Use of Waters by Others

Rocky Island Lake	Water Supplied from Storage to Support Fisherman's Water (Water for Navigation by Sports Fisherman) During July, August, September
Aubrey Falls GS	Scenic Water for Aubrey Falls
Rayner-Wells GS	
Red Rock Falls GS	Fisherman's Water Water Level Fluctuations - 2 feet/day August 1st Raft Race

Implementation Of Allocation Process

Once the various constraining factors are understood on a watershed, the process of allocation can proceed. This is a dynamic process, requiring constant attention from the operators of the control system.

The hydrologic state of the watershed is continually monitored and, based on the available information on streamflow, reservoir levels, precipitation, etc, forecast of future conditions are made. Forecasts are critical to the allocation process since problems of over-or under - supply of water can only be prevented by advance planning and action. Due to the inertia of river systems, once a critical supply system exists, it cannot be corrected. Corrective action must be taken before the process becomes irreversible.

Once forecasts have been made and the quantity of water available to satisfy the requirements of the various users is known, it is allocated. In times of short supply (drought) the existence of hydro-electric operations may increase the amount of waters available to non-utility users, and vice versa in times of flood. These operations, while not giving other users the optimum water conditions, result in conditions which are better than would have realized under an uncontrolled regime. They can often be achieved at little or no cost to power.

It is Ontario Hydro's practice to cooperate with other users but not always to make conditions perfect for them, specifically during time of hydrologic extreme.

Conclusions

Water resource based activities of all types are increasing throughout our society. As a result, hydroelectric power producers must realize that the water resource must be shared amongst many users, and we must accept this fact voluntarily or face the risk of having our operations severely constrained by legislation.

At the same time, the utilities must jealously guard their legitimate rights to rivers and reservoirs and attempt to ensure that these rights are not gradually whittled away for the benefit of a few users at the cost to society as a whole.

Federal Water Policy And Interests

Presented by R. RIVERS
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Preamble

I am pleased to be here today and to have been asked to speak to you during this workshop session. I would also like to introduce Mr. Ted Moenig of Inland Waters/Lands - Ottawa who has joined me to assist with any questions that may arise in the course of the workshop.

Before proceeding with my presentation, let me say that Peter Pearse was commissioned in 1984 to bring forth a set of recommendations for a federal water policy. Even as I speak, actions on these recommendations are progressing towards an official policy. While I have seen drafts of the policy I will restrict myself from being too specific about that paper at this early stage.

Introduction

For those involved in water management on a day-to-day basis, the role, importance, and value of water need little articulation. We inherently recognize water as a vital component of our existence, prosperity, and environment. Besides its life-supporting sustenance to man and ecological systems, water is incessantly at work in natural physio-bio-geo-chemical processes, in the assimilation of man's waste products, and in turning the massive turbines of man's economic machine. In other dimensions, where man's activities have become ingrained and inflexible, water takes on a more onerous mask: inflicting health hazards by transmitting the diseases and toxics pooled by the waste effluents, inflicting damages to life and property through its natural course of flooding and erosion, inflicting hardships such as droughts in its natural cycle.

Water is, thus, very much a natural resource; but a resource with both positive and negative connotations within our own human framework. It differs greatly, moreover, from other resources such as forests or minerals because it is constantly moving, changeable, and dynamic. It is a resource in motion and can more poetically be termed an "emotional resource" which reflects and reacts to changing conditions and situations.

Like so many other elements and aspects of our natural environment, water has long been taken for granted. It has taken time with the evolution of societies and technology for minor problems and inconveniences to be realized as major problems and potential disasters. It has equally taken time for our experience, perception, and knowledge to achieve a level sufficient to undertake to "manage" water rather than merely use or exploit it, to live and cope with its many dimensions rather than be

victimized by it.

Such are, generally, the considerations which colour the broad backdrop against which any systematic approach to dealing with water and water-related problems must be framed. Water policy in Canada has evolved and continues to evolve over time. Historically, policies have been reactionary to threatening problems and situations; and at other times, anticipatory. As fragmented and confused as were our earlier perceptions, water policy in the future may optimistically mirror more closely the better understanding of interactions between man's activities and the dynamic nature of water.

Federal Water Policy

Basis

Responsibility and jurisdiction over **water** issues/matter stems from *Constitution Acts of 1867 (British North America Act) and 1982.* Unfortunately, water is never specifically mentioned (surprisingly even in the 1982 Act) and is left for determination by interpretation and analogy.

Prime jurisdictional authority is given to the provinces; therefore provinces are the main "water managers" and can determine its apportionment and regulate its quality to meet provincial economic and social objectives. Sec. 109 and 92 of Constitution Acts give the provinces ownership of public lands, minerals, etc. (and therefore rivers and water courses); management and sale of public lands, local works; generally all matters of local/private nature in province; exclusive powers over development, control, management of sites and facilities for hydroelectrical power.

The only restrictions to provincial powers in water management are *federal powers stemming from the same constitutional basis.* These involve federal lands, navigation and fisheries, over which the federal government has direct jurisdiction.

There are also other federal powers which can indirectly influence provincial authority over internal waters: *statistics (sec. 91(6))* - data on water supply, quality, use; - *agriculture* - irrigation projects, control of pollutants affecting agriculture; *"spending" power* - grants/contributions to provinces with provisions to steer/direct provincial policies and priorities; *treaty power (sec. 132)* - fulfill obligations of international treaties (eg. Boundary Waters Treaty; *declaratory power (sec. 92(10)(a)-(c), 91)* - may exert authority over works in a province by declaring them for general national benefit or for the benefit of other provinces where the effects of works extend beyond the province; or legislating for "peace, order, and good government" on any matter not exclusively assigned to provinces.

Federal Water Policy in Legislation

Federal water policy is thus based on the preceding considerations and formulated in a number of acts/legislation, etc.:

Fisheries Act — gives the federal government responsibility for the protection and conservation of fisheries resources and habitats; it can regulate local works to ensure maintenance of fish passage, protection of spawning, nursing, habitat areas from physical disturbance and pollution detrimental to fish.

Navigable Waters Protection Act — the federal government has exclusive authority over navigation and shipping, control design and construction of any structure that may interfere with navigation, - disposal of rubble or other material into

navigable waters, etc.

Boundary Waters Treaty Act (1909) — assigns federal responsibility for protection of open and free navigation between Canada/US; maintenance of natural flows and levels of boundary waters (excluding tributaries); prevention of transboundary pollution.

Can/US Great Lakes Water Quality Agreement (1972, 1978) was established to deal with lower Great Lakes pollution problems;, - allows fed/prov agreements relative to meeting international obligations, eg. Can/Ont Agreement re: Great Lakes Water Quality.

Migratory Birds Convention Act (1916) — enables protection of birds from water pollution.

Canada Water Act (1970) — allows for comprehensive water management projects, either unilateral federal action on interjurisdictional basins to support the province where there is significant national interest; for interprovincial water planning activities; establishment of water management agencies to plan, implement programs, etc. in designated (by agreement) areas.

Northern Inland Waters Act (1970) — essentially reflects federal role as water manager/provincial counterpart in Territories, also Indian lands.

International River Improvement Act (1958) — provides for regulation of construction, operations, maintenance of river modifications affecting international waters.

Arctic Waters Pollution Prevention Act (1970); Canada Shipping Act (Amended 1970) — provide for control of ocean dumping, disposal of ship wastes, etc.

Environmental Contaminants Act (1975) — provides grounds for restricting manufacture and distribution of toxic chemicals (only 5 substances listed to date).

Canadian Heritage River Systems Act (1983) — allows provinces to nominate waterways for protection.

Other relevant acts, statements, programs: Government Organization Act (1979) — Department of Environment — given role re: water and measures to control environmental quality; 1974/77/85 - *Federal Environmental Assessment and Review Process* — requires environmental assessments for all federal projects; 1975 - *Flood Damage Reduction Program* — aimed at discouraging new investments in vulnerable flood risk areas; *Department of National Health and Welfare* — Canadian Drinking Water Standards (1968), revised 1978, currently being expanded; *Department of Agriculture* — water for farm production; Can/Ont Soil and Water Enhancement Program (1986) - aimed at reducing phosphorus loadings in Lake Erie Basin from agricultural run-off and reducing soil erosion; *Energy, Mines, and Resources* — water-energy programs; *Department of Regional Industrial Expansion* (formerly Reg. Economic Expansion) now Ministry of State for Industry/Science and Technology — financial incentive programs for infrastructure, etc.; *Prairie Farm Rehabilitation Act* — fed. government assistance and participation in community water supply projects; *National Energy Board (1959) & Atomic Energy Control Act* — provide for regulation of power exports and nuclear power industry, respectfully.

Other indirect — Clean Air Act, Transportation of Dangerous Goods Act, Pesticides Control Act.

Overview Look On Water Policy

The preceding notes on relevant legislation indicate what legal instruments are in place at the federal level to direct federal water programs. While it is useful to

note that most pieces of legislation were introduced in response to problems, the Boundary Waters Treaty in retrospect is also anticipatory since it has provided/facilitated subsequent agreements to deal with even the most current of problems, eg. toxic chemicals. It could be said that water policy is relatively fragmented over various pieces of legislation and various federal agencies. The original Canada Water Act document of 1968 called for the creation of an Interdepartmental Committee on Water (ICW) which was to consider/approve/direct all federal water programs. No action was taken until 1975 when terms of references were revised to better reflect the intent of the Cabinet document and the ICW is still not performing at its full potential.

This section attempts to provide briefly a more holistic view of the federal government's water management programs and thrusts which, thereby, constitute its water policy. The recent (Pearse) Federal Inquiry on Water has attempted to come to grips with the federal role in water management and some of their recommendations are touched upon towards the end of this presentation.

Basically, the federal water programs could be grouped into three categories, recognizing that there will always be certain overlaps: water quantity, water quality, and water use. The federal role in water research is substantial and quite naturally permeates all categories. Data collection, planning regulatory, and advisory functions are also pertinent to all categories.

Water Quantity — the collection of hydrometric data (streamflow, water levels, sediment transport), etc., has been an ongoing service for a long time; a 1975 Order-in-Council formally established a National Water Quantity Survey with specific guidelines to determine federal interest in a national network of data collection stations; - designations of fed (100%), fed/prov (50/50%), or prov (100%) govern the funding support for the stations; - data used to support flood forecasting, lake and reservoir regulation, planning/operating hydroelectric stations, irrigation, navigation, industrial/municipal works; - for example, in 1982 out of network of 3074 stations, 1182 designated federal; water quantity support is given to 12 International Boards of Control (water levels and flows), and investigative boards (as occasionally necessitated; scope of study usually broadened to also consider water quality and use); the Flood Damage Reduction Program is implemented through fed/prov agreements (50/50 funding) and aimed at discouraging development in flood-prone lands and thereby to eliminate claims for disaster assistance. The main activity is to map and designate flood risk areas, conduct studies in flood forecasting, flood-proofing, etc. Fed/prov FDR Agreements provide for no fed/prov investments in designated flood-risk areas.

Water Quality — The new *National Water Quality Assessment Policy* is aimed to provide scientific/technical information data, monitor status and trends of water quality in water bodies, detect emerging problems, using an approach similar to that of the National Water Quantity Survey: stations are designated as fed, fed/prov, prov based on interest and watershed. Federal stations are to support programs in international/interjurisdictional waters, native/federal lands, toxic chemicals, LRTAP, control of nutrients/eutrophication; - special studies to advise IJC; - the policy includes set up of central national water quality labs and provisions for quality control in provincial labs. A *major effort involves the Great Lakes, Can/US GLWQA, subsequent Can/Ont GLWQA (or COA-1982, latest)*; among undertakings in this area could be identified some of the following measures: CMHC funded (for a time)

the provision/upgrading of municipal sewage treatment systems for phosphate removal (federal ban on phosphates in detergents legislated also) — (prov role mainly concerned with impact of urban drainage, effects of municipal abatement measures; also monitor tributary water quality and pollutant loadings). The GLWQ program comprises 13 activities which include: the elimination of pollution from municipal sources, industrial sources, from land use activities, shipping, on-shore/offshore facilities, inventory of pollution, abatement requirements, eutrophication reduction, hazardous polluting substances, persistent toxic chemicals, airborne pollutants, compliance surveillance, emergency contingency plans to contain/clean up oil spills or other hazardous polluting substances.

With respect to *toxic chemicals*, multi-departmental efforts including Environment, Agriculture, Transport, Atomic Energy Control Board, National Health and Welfare, External Affairs/IJC, Indian and Northern Affairs and DFO are directed by an Interdepartmental Committee on Toxic Chemicals. These efforts address risk assessment (review procedures to identify hazards), risk management (balance soc-econ benefits and health/environmental risks), and enforcement/compliance - intention to draw up 3 year toxic chemical action plan on 5 priorities: drinking water safety, dioxins, pesticides, contaminants of fish, indoor air quality. Among other related programs are the: *drinking water safety program* — aimed to promote protection of national drinking water and appropriate treatment of drinking water supplies (primarily EC and NHW); *Long Range Transport of Airborne Pollutants* — aim to reduce acidic depositions and damages/effects to aquatic life, waterfowl, human health — water management support to negotiation of control measures with US, monitoring trends in water chemistry/atmospheric loadings, characterize pathways, cause/effects, etc., risk assessment, negotiation of fed/prov agreements to reduce domestic emissions (program in some difficulties with respect to effectiveness, coordination).

Water Use — In terms of water use, the main federal concerns pertain to navigation and fisheries: ie. protection/maintenance of waterways for purposes of navigation (Transport Canada), protection of fisheries and habitat (note that the main enforcement sections of Fisheries Act transferred to provinces (Ontario) or administered by Environmental Protection Service). There is a growing level of activity directed specifically to water use in terms of water supply and demand management. This had generally been included in water quantity programs as support to water level/flow control boards, occasional studies touching on water use (eg. GL Diversions and Consumptive Uses), EC Climate Change Study - effects on GL/Ont Region water uses; statistical data collection on water usage by various sectors; current work undertaken re: water conservation and water pricing; some comprehensive river basin studies undertaken under the Canada Water Act through fed/prov agreement, or through funding provided by ERDA's.

Notes On Federal Inquiry On Water

Federal water policy has been based on supporting activities such as fisheries, agriculture, navigation, etc. The federal government relies to a great extent on fed/provincial cooperation to effect that policy. *Federal water policy consists of not only objectives but also for the means to meet them: legislative, institutional, administrative arrangements, and all other instruments/procedures that affect how water is used and developed.*

Federal water policy could alternatively be considered in three other directions (from that given above), ie. specific water uses (navigation, fisheries, agriculture), water quality protection (general to particular pollutants), and International Treaty obligations.

Main areas of Inquiry recommendations:

1. adopt integrated watershed management as principle of federal water policy;
2. Encourage water conservation and demand management practices on user pay principle;
3. apply comprehensive and consistent criteria to evaluation of water development projects;
4. cautiously approach issues of interbasin transfers and then only after all alternatives weighed and appropriate evaluations made;
5. fed/prov consultation on improving/financing municipal infrastructure;
6. undertake thorough study of appropriate pricing for municipal water/waste water services;
7. establish minimum drinking water standards;
8. establish a fed/prov agreement on water quality guidelines for major water uses;
9. develop more effective control over toxic substances and hazardous wastes;
10. increase efforts to pursue acid rain control.

Water-related Legislation And Programs Of The Ontario Ministry Of Natural Resources

D.L. Strelchuk, Ontario Ministry of Natural Resources

Under the Constitution Act the allocation and management of resources, including water, fall under provincial jurisdiction. This responsibility is shared by a number of Provincial agencies, primarily the Ministry of the Environment (MOE) and the Ministry of Natural Resources (MNR).

Generally, MNR manages water quantity and MOE is responsible for water quality. However, the goals and program objectives often overlap. This discussion will focus only on MNR legislation and programs.

MNR Water-Related Legislation

The *Lakes and Rivers Improvement Act* requires approval for the construction of works in the water. Works are defined as any measure which forwards, holds back or diverts water. Dams, diversions, channelization, river improvements and shore protection are considered as works. The criteria used in the approval process requires that the work be located and designate so it will:

- not interfere with the exercise of public rights in or over water.
- permit adequate flow past the work to meet established downstream uses.
- not flood other property.
- not adversely affect water quality and other natural amenities of the water.
- minimize erosion and silting in the stream.
- not destroy, damage or interfere with fish and wildlife habitat or other natural resources dependent on the water.
- be safe.
- not require frequent repairs.

The Bed of Navigable Waters Act places land that borders on or is in a navigable body of water under Crown ownership in the absence of an express grant to their ownership. This places most beds of lakes and rivers and some shoreline areas bordering lakes under Crown ownership and is within the administration mandate of MNR.

The Public Lands Act stipulates that no structure or matter may be situated on public land without approval. Land which forms the beds of navigable streams and lakes is generally public land, unless specifically included in a lease or other tenure document. MNR, in addition to having management responsibility for the public land base, is responsible for the management of the forest, water, fish and wildlife resources all of which are affected by the types of uses of Crown Lands. The objectives of managing Crown Lands are to ensure that the greatest benefits are derived for the public.

The Beach Protection Act requires an MNR licence for the taking of sand from the bed, bank, beach, shore or waters of any lake, river or stream. The main criteria used in evaluating effects are that the removal should not unduly impair or interfere with the natural state or use of waters or likely cause undue erosion. Licences must be renewed annually.

The Conservation Authorities Act provides for the establishment of a Conservation Authority as a corporate entity comprised of member municipalities within a watershed. This allows the management of water on a watershed basis. The objectives of a Conservation Authority (CA) are to establish programs in their watershed to further the conservation, restoration, development and management of natural resources other than gas, oil, coal and minerals. Projects are initiated by member municipalities with program approval and cost-sharing with MNR.

CAs have focused most their attention to solving flooding problems. The Act enables CAs to register regulations which control construction and fill in regulated flood plains to prevent loss of life or property. However, under the broad mandate a diversity of programs have been undertaken. These include construction of dams and reservoirs, acquisition of lands for park or recreational purposes, wetlands management, soil conservation and others.

The Fisheries Act is a federal statute forbidding any work or undertaking that results in the harmful alteration, disruption or destruction of fish habitat. Fish habitats are defined as spawning grounds and nursery, rearing, food supply and migration areas on which fish depend, directly or indirectly, in order to carry out their life processes. MNR has been delegated by the Federal government with the administrative responsibility for fisheries management within the province. Ontario's Conservation Officers as designated as Fishery officers for purposes of administering the Fisheries Act.

The Game and Fish Act provides for the management, perpetuation, and rehabilitation of the wildlife resources in Ontario and to establish and maintain a maximum wildlife population consistent with all other proper uses of lands and waters. The Act allows for management agreements with landowners to carry out habitat improvement work, protective measures, stocking programs and other management practices. The Act also sets out fishing and hunting regulations.

The Endangered Species Act provides for the protection of species threatened by extinction through overfishing, habitat destruction, diseases and uses of chemicals.

MNR Programs

Fish Habitat Management

A Canada-Ontario Fisheries Agreement under the Fisheries Act is pending with the objective of managing habitat for fisheries resources. The goals are to conserve existing fish habitat,restore damaged fish habitat and develop or enhance fish habitat.

Implementation strategies will be those outlined in "Summary, Fish Habitat Management Policy" prepared by Fisheries and Oceans. They are as follows:

1. Protection and Compliance

Protect fish habitats by administering the Fisheries Act and incorporating fish habitat protection requirements into land and water activities and projects.

2. Integrated Resource Planning

Participate in and encourage resource planning and management among all concerned government agencies and private sector interests and to incorporate fish habitat priorities into air, land and water use plans.

3. Scientific Research

Conduct scientific research to provide the information and technology necessary for the conservation, restoration and development of fish habitat.

4. Public Consultation

Consult the public on major or controversial fish habitat issues and in the development of new policies and legislation for fish habitat management.

5. Public Information and Education

Promote public awareness in the conservation, restoration and development of fish habitats.

6. Cooperative Action

Encourage and support involvement by government agencies, public interest groups and the private sector to conserve, restore and develop fish habitats and promote the establishment of national and regional committees, foundations or boards to work cooperatively with the Department.

Existing fisheries habitat management programs include:

1) Habitat rehabilitation of damaged habitat
2) Community Fisheries Involvement Program (CFIP) which encourages the public to restore and replace damaged fish habitat
3) habitat protection-using the various legislation
4) Research - (Fisheries Branch)
5) Assessment
6) Inventory

Wetlands Management

A policy statement on wetlands planning is being prepared under Section 3 of the Planning Act with the objective of conserving provincially significant wetlands in southern Ontario. This will require all planning agencies to have regard for wetlands in the municipal and provincial planning process.

A program of wetlands acquisition is presently underway.

Environmental Assessment

MNR is obligated by Order in Council to ensure that all Ministry activities fulfill the Environmental Assessment Act requirements. Class Environmental Assessments have been developed for most MNR activities. A Class Environmental Assessment is defined as an environmental assessment which applies to a group or class of similar activities and for which time and location are not specified.

Summary

A summary of MNR water-related legislation and programs is given in Table 1. Figure 1 shows the administrative districts and regions of MNR. Table 2 provides the addresses and telephone numbers of MNR District Offices.

Table 1

Legislation	**Administered By**
Lakes and Rivers Improvement Act	District Office
Beds of Navigable Waters Act	Land Management Branch, Toronto
Public Lands Act	District Office
Beach Protection Act	District Office
Conservation Authorities Act	Conservation Authorities and Water Management Branch, Toronto
Fisheries Act	Fisheries Branch, Toronto
Game and Fish Act	Wildlife Branch, Toronto
Endangered Species Act	Wildlife Branch, Toronto
Program	
Canada-Ontario Fisheries Agreement	Fisheries Branch, Toronto
Habitat Rehabilitation	Fisheries Branch, Toronto
Community Fisheries Involvement	Fisheries Branch, Toronto
Fisheries Research	Fisheries Branch, Toronto
Fisheries Inventory	Fisheries Branch, Toronto
Wetlands Wildlife Branch, Toronto	
Class Environmental Assessments	Policy and Planning Secretariat, Toronto

References

Ontario's Public Land, A Guide to Its Use, Ministry of Natural Resources, 1978.

Building a Dam and Other Water Projects, Ministry of Natural Resources, 1983.

Guidelines for Wetlands Management in Ontario, Ministry of Natural Resources, 1984.

An Evaluation System for Wetlands of Ontario, Environment Canada/Ministry of Natural Resources, 1985.

Canada's Fish Habitat Law, Fisheries and Oceans Canada, 1983.

Summary, Fish Habitat Management Policy, Fisheries and Oceans Canada, 1986.

Environmental Assessment Procedures Manual for MNR Activities, MNR.

Construction and Mitigation Handbook for MNR Class Environmental Assessment Projects, MNR, 1984.

Figure 1: Administrative Districts and Regions Ministry of Natural Resourses

Table 2: District Offices in the Ministry of Natural Resources

Atikokan
108 Saturn Avenue
P0T 1C0
(807) 597-6971

Aylmer
353 Talbot Street West
Box 940, N5H 2S8
(519) 773-9241

Bancroft
Box 500, K0L 1C0
(613) 332-3940

Blind River
62 Queen Avenue
Box 190, P0R 1B0
(705) 356-2234

Bracebridge
Box 1138, P0B 1C0
(705) 645-5244

Brockville
Box 605
K6V 5Y8
(613) 342-8524

Cambridge
Box 2186, Beaverdale Road
N3C 2W1
(519) 658-9356

Carleton Place
10 Findlay Avenue
K7C 3Z6
(613) 257-5735

Ottawa Work Centre
Ramsayville, K0A 2Y0
(613) 822-2525

Chatham
435 Grand Avenue West
Box 1168, N7M 5L8
(519) 354-7340

Chapleau
34 Birch Street
P0M 1K0
(705) 864-1710

Cochrane
2 Third Avenue
Box 730, P0L 1C0
(705) 272-4365

Cornwall
Box 1749, 113 Amelia Street
K6H 5V7
(613) 933-1774

Dryden
Box 3000, P8N 3B3
(807) 223-3341

Espanola
Box 1340, P0P 1C0
(705) 869-1330

Fonthill
Highway 20, Box 1070
L0S 1E0
(416) 892-2656

Fort Frances
922 Scott Street
P9A 1J4
(807) 274-5337

Geraldton
Box 640, P0T 1M0
(807) 854-1030

Gogama
P0M 1W0
(705) 894-2000

Hearst
Box 670, P0L 1N0
(705) 362-4346

Ignace
Box 448, P0T 1T0
(807) 934-2233

Kapuskasing
6 Government Road
P5N 2W4
(705) 335-6191

Kenora
808 Robertson Street
Box 5080, P9N 3X9
(807) 468-9841

Table 2: (cont.)

Lindsay
322 Kent Street West
K9V 4T7
(705) 324-6121

Maple
R.R. No. 2, L0J 1E0
(416) 832-2761

Midhurst
L0L 1X0
(705) 728-2900

Minden
K0M 2K0
(705) 286-1521

Moosonee
Box 190, P0L 1Y0
(705) 336-2987

Napanee
1 Richmond Blvd.
K7R 3S3
(613) 354-2173

Nipigon
Box 970, P0T 2J0
(807) 887-2120

North Bay
Box 3070, P1B 8K7
(705) 474-5550

Owen Sound
611-9th Avenue East
N4K 3E4
(519) 376-3860

Parry Sound
4 Miller Street, P2A 1S8
(705) 746-4201

Pembroke
Riverside Drive, Box 220
K8A 6X4
(613) 732-3661

Red Lake
Forestry Road Box 323
P0V 2M0
(807) 727-2253

Sault Ste. Marie
69 Church Street Box 130
P6A 5L5
(705) 949-1231

Simcoe
645 Norfolk Street North
N3Y 3R2
(519) 426-7650

Sioux Lookout
Box 309, P0V 2T0
(807) 737-1140

Sudbury
P.O. Box 3500 Station A
P3A 4S2
(705) 522-7823

Swastika
P.O. Box 129, P0K 1T0
(705) 642-3222

Temagami
Box 38, P0H 2H0
(705) 569-3622

Terrace Bay
P.O. Box 280, P0T 2W0
(807) 825-3205

Thunder Bay
435 James Street South
P.O. Box 5000, P7C 5G6
(807) 475-1511

Timmins
896 Riverside Drive
P4N 3W2
(705) 267-7951

Tweed
Metcalfe Street
K0K 3J0
(613) 478-2330

Wawa
22 Mission Road
Box 1160, P0S 1K0
(705) 856-2396

Whitney
Box 219, K0J 2M0
(705) 637-2780

Wingham
Box 490, Highway No. 4 South
N0G 2W0
(519) 357-3131

Main Office Toronto
Parliament Bldgs.
M7A 1W3
(416) 965-1271

Ministry of the Environment - Interests

K.E. Willson

In this presentation to you this morning I would like to touch on four areas; the mandate of the Ontario Ministry of the Environment, the major piece of legislation which the Ministry administers, some of the major programs of the Ministry, and finally how the Ministry fits into the theme of this workshop series "Managing Ontario's Streams". Given the time constraints I will limit this presentation to water related issues.

Part I

The Mandate of the Ministry of the Environment

The Ontario Ministry of the Environment has adopted the following corporate goal:

"To achieve and maintain a quality of the environment - including air, water and land - that will protect human health and the ecosystem and will contribute to the well-being of the people of Ontario".

With respect to surface waters the two major goals are:

1) "To ensure that the surface waters of the Province are of a quality which is satisfactory for aquatic life and recreation".
2) "To ensure a fair sharing of the available supply of water to protect both withdrawal and in-place uses of water".

Implied in goal no.1 is the assumption that water which meets the water quality criteria for aquatic life and recreation, will be suitable for most other beneficial uses, such as drinking water and agriculture.

To achieve these goals the Ministry has defined a series of policies with respect to surface quality and quantity management. These policies are outlined below.

Surface Water Quality Management

Policies

1) In areas which have water quality better than the Provincial Water Quality objectives, water quality shall be maintained at or above the objectives.
2) Water quality which presently does not meet the Provincial Water Quality Objectives shall not be degraded further and all practical measures shall be taken to upgrade the water quality to the Objectives.
3) Effluent requirements will be established on a case-by-case basis. In establishing effluent requirements, the characteristics of the receiving water body will be considered, as will Federal and Provincial effluent regulations and guidelines where applicable. The effluent requirements so derived will be incorporated into Certificates of Approval and will specify both waste loadings and concentrations.

4) Special preventive measures are required to deal with the release of known or potentially hazardous substances. Accordingly, the Ministry's policy is to:

i) prevent the release of those substances listed in Table 2 (this is a table of substances which have been defined to have a zero tolerance limit and is included in the "Blue Book" which is described below) which are hazardous if released in any concentration;

ii) ensure that special measures are taken on a case-by-case basis to minimize the release of any substances for which Provincial Water Quality Objectives have not yet been established.

5) A mixing zone is defined as an area of water contiguous to a point source where the water quality does not comply with the Provincial Water Quality Objectives. Terms and conditions related to a mixing zone will be designated on a case-by-case basis and may be specified in Certificates of Approval, control orders, requirement and directions, or approvals to proceed under the Environmental Assessment Act. The size of the mixing zone shall be minimized to the greatest possible degree and under no circumstances is the mixing zone to be used as an alternative to treatment.

Surface Water Quantity Management

Policies

1) The withdrawal of water from and discharge of water to surface water bodies will be controlled to assist in maintaining or restoring water quality for the protection of aquatic life and recreation.

2) Surface water takings will be controlled to prevent interference with other uses of water wherever possible and to resolve such problems if they do occur.

3) All reasonable and practical measures should be taken to conserve the quantity of surface water, in order to maximize its availability for existing or potential beneficial uses.

In order to carry out the multitude of tasks associated with the above goals the ministry is divided into a series of divisions and branches. Figure 1 illustrates the organizational structure of MOE as it was in 1986.

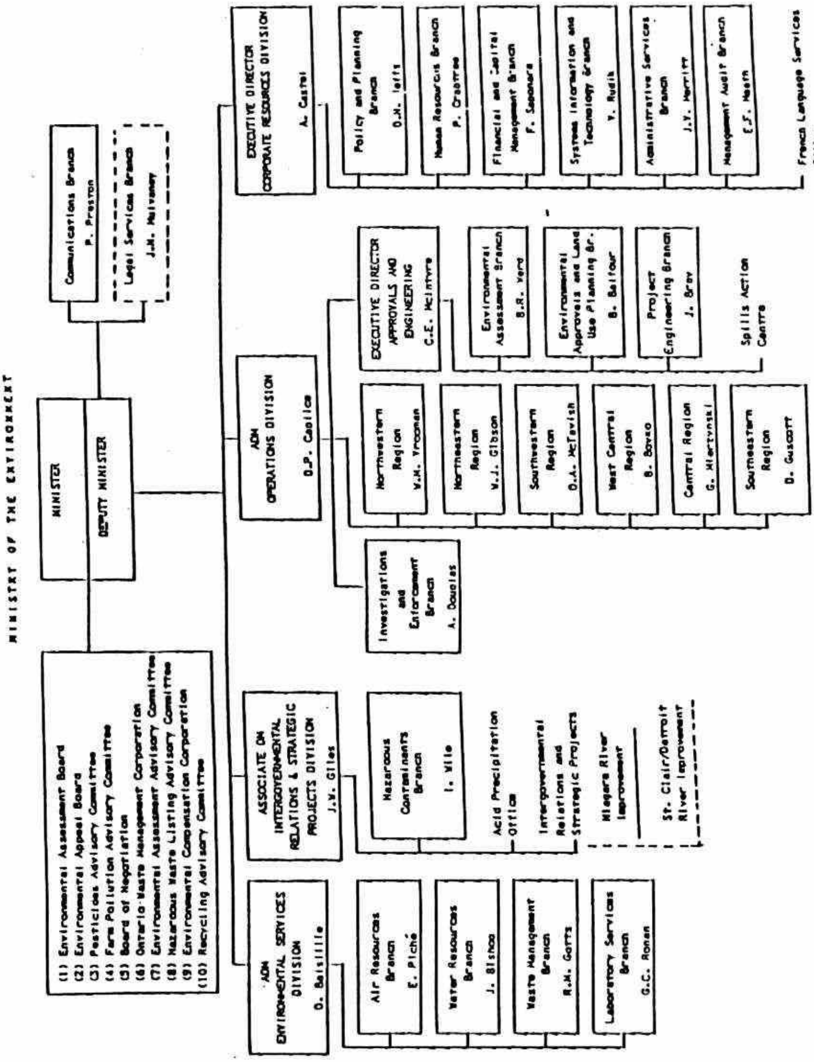

Figure 1: Organizational Structure of the Ministry of the Environment (1986)

The two main divisions which deal with water related issues are; the Environmental Services Division and the Operations Division. The Environmental Services Division is responsible for providing scientific, technical and laboratory support services, and for developing programs dealing with waste management, air and water resources, for the protection of the ecosystem and human health. The Operations Division is responsible for operations and program delivery. It is also responsible for delivering programs to protect air quality, to protect surface and ground water quality and quantity, to manage the disposal of wastes, to ensure an adequate quality of drinking water, to control the use of pesticides, and to assist in the funding of municipal water and sewage servicing projects.

The branches with interests in water related issues are; Water Resources, Waste Management, Hazardous Contaminants and Standards, Environmental Assessment, Policy and Planning, Environmental Approvals and Project Engineering and the Regional Offices.

The following is intended to provide a brief overview of the primary roles of each of these branches.

Water Resources Branch

Role: To develop and monitor the results of plans and programs:

a) to protect and upgrade water quality in lakes, rivers, streams and ground water;

b) to develop water resources and provide for the fair sharing and conservation of available resources for multiple uses;

c) to protect the public from contaminants in water and fish

Waste Management Branch

Role: To develop plans and programs to manage the generation, reuse, collection, transportation, treatment and disposal of domestic, commercial and industrial wastes and to monitor their results.

Hazardous Contaminants and Standards Branch

Role: a) To assess the significance of hazardous contaminants and coordinate Ministry activities for their control;

b) To establish standards for the protection of public health and the environment.

Environmental Assessment Branch

Role: To promote the consideration and inclusion of environmental, social and economic alternatives in the planning and development of undertakings.

Policy and Planning Branch

Role: To evaluate the Ministry's policies, programs, and resource needs and to coordinate management and efficient utilization of Ministry resources.

Environmental Approval and Project Engineering Branch

Role: a) To review and process applications required under the Environmental Protection Act, the Ontario Water Resources Act and the Pesticides Act.

b) To promote the consideration of the environment in land-use policies and

programs.

c) To encourage the development of a water supply and sewage treatment infrastructure through the provision of engineering and construction assistance to municipalities.

The six regional offices fall under the jurisdiction of the Operations Division, thus their emphasis is on delivery of the programs developed in the head office branches. Programs such as utility operations, emergency spill response, complaint investigation, inspections, etc. are all administered by the Regional offices.

Part II

Major Pieces of Legislation

There are three major pieces of legislation which the Ministry applies with respect to its role in managing Ontario's streams; the Environmental Protection Act, the Environmental Assessment Act, and the Ontario Water Resources Act. The following is a brief summary of these acts.

The Environmental Protection Act

The purpose to the Act is "to provide for the protection and conservation of the natural environment". It is used primarily to protect and conserve the natural environment against pollution. The Act tends to be somewhat reactive in it's nature as the provisions of the Act can only be used when the environment is contaminated by a contaminant.

The two main provisions of the Act which deal with pollution and water issues are:

1) "no person shall deposit, add, emit, or discharge a contaminant or cause or permit the deposit, addition, emission or discharge of a contaminant into the natural environment that,

a) causes or is likely to cause impairment of the quality of the natural environment for any use that can be made of it;

b) causes or is likely to cause injury or damage to property or the plant and animal life;

c) causes or is likely to cause harm or material discomfort to any person;

d) adversely affects or is likely to adversely affect the health of any person;

e) impairs or is likely to impair the safety of any person; or

f) renders or is likely to render any property or plant or animal life unfit for use by man".

2) "no person shall deposit in, add to, emit, or discharge in to natural environment and contaminant... in an amount, concentration or level in excess to that prescribed by the regulation".

The Environmental Assessment Act

The basic purpose of the Act is to stop environmental damage before it starts, and to permit some public participation in the environmental decision-making process. The Act provides an approval process through which many activities which may have an impact upon the environment must pass before they are undertaken. The Act does not provide for a right to environmental quality, only to environmen-

tal impact assessment. The Act makes no provision for small projects which may have a large cumulative impact.

The Ontario Water Resources Act

Under this Act, the Minister is given the mandate to supervise all surface and ground water in Ontario. His powers include regulation of private enterprises with respect to their effect on water quality and making regulations prescribing standards of quality for industrial effluent.

The main provisions of the Act are "every municipality or person that discharges or deposits or causes or permits the discharge or deposit of any material of any kind into or in any well, lake, river, pond, spring, stream, reservoir or other water or watercourse or any shore or bank thereof or into or in any place that may impair the quality of the water...is guilty of an offence". The Act goes further to define an impairment as "the quality of water is deemed to be impaired if the material deposited or discharged...causes or may cause injury to any person, animal, bird or other living thing as a result of the use or consumption of any plant, fish or other living matter or thing in the water or in the soil in contact with the water".

In order to allow for the discharge of materials such as properly treated sewage, the Act contains a provision which allows for the discharge into any watercourse of sewage from sewage works which have been constructed and are operated in accordance with the regulations set down by the ministry.

Part III

Ministry Programs

Most of you are probably familiar with a few of the myriad of programs which the Ministry administers. These programs cover the whole range from monitoring, investigation, enforcement and prosecution to interministerial cooperative grant programs. I would like to briefly describe a few of these programs with emphasis on investigation, pollution, control and water quality management.

MISA

To start off I would like to describe what is probably the most ambitious program being undertaken by the Ministry; the Municipal and Industrial Strategy for Abatement or MISA as it is known. Under this program a total of approximately 700 direct dischargers and about 12,000 indirect dischargers in the Province will be required to report data on their discharges on a routine basis. This is a program of self monitoring and reporting with a liberal amount of quality control through a routine random split and replicate sampling procedure. When it is fully implemented the Ministry will be receiving between 500,000 and 1,000,000 pieces of data per month.

Following closely upon this monitoring phase is a compliance phase which is a combination of effluent compliance regulation setting and a requirement for the adoption of Best Available Technology which is Economically Achievable (BATEA).

A second component of MISA is the receiving water track. In this component, effluent limits will be calculated through the collection and analysis of data on water quality, effluent quality, sediments, aquatic life, and stream and effluent quantity. A modelling approach will be used to assess the impacts on the receiving stream and thereby develop a set of site-specific effluent limits. These will be compared

to the BATEA requirements for that sector, and the more stringent limits will be imposed.

Sewage Treatment

Municipal wastewater treatment plants in Ontario may be owned and/or operated by the municipality or the Province. More than 400 such facilities exist in Ontario today treating waste from approximately 7.1 million people. The remainder of the population is serviced by private treatment systems.

The province provides grants on a sliding scale ranging between 15% and 85% for municipalities constructing new or expanding existing treatment facilities. The exact amount of the grant is tied into the population serviced by the facility.

Drinking Water

A similar program exists for the provision of an adequate supply of drinking water for the people of Ontario. In addition, two other programs exist. The DWSP or Drinking Water Surveillance Program is a comprehensive network of sampling locations in municipal drinking water plants and supply systems. The data are archived at the Water Resources Branch and summaries of results are issued periodically.

The water well records program maintains an up to date file of all wells drilled within the Province. Licensed drilling contractors are required to submit a detailed drilling record on every well they drill whether it yields water or not. The record includes such information as well depth, geology, exact location and the results of the pumping test. This information is maintained on file at the Water Resources Branch.

Blue Book

The MOE publication "Water Management", or the Blue Book, as it has come to be known, lists the water quality goals, policies, objectives and guidelines established by the Ministry described earlier in this paper. The Blue Book was first published in 1978 and underwent a minor revision in 1984. The Blue Book is presently undergoing a major review and revision as part of the MISA program.

Beaches Program

The Ministry operates a program designed to improve the water quality at all urban and rural beaches in ontario. This is a ten year, multi-million dollar program which provides monies for both research and capital works implementation. For urban beaches the monies are granted to municipalities while for rural beaches grants are made to the local Conservation Authority to carry out source identification, public education, and develop remedial action plans.

The program is very progressive in its design in that the local technical steering committees are made up of representatives from each agency with an interest in the project. Representation typically comes for MOE, OMAF, MNR, MOH, conservation authority, OFA, and possibly a private farmer.

A Provincial Committee which is comprised of representatives from MOE, OMAF, MNR overviews the whole program. It should be noted that the chairpersons from each of the technical steering committees also sit on the Provincial committee. This assures a cross communication of information between all the projects.

Spills

The Ministry now operates a Spills Action Centre (SAC) to provide for emergen-

cy response to spills throughout the Province on a 24 hour basis. Through the spills bill which was introduced in 1986 the spiller is required to pay the cost of cleaning up the spill. In addition, through the fast action of its regional duty staff, the Ministry can now be on the site of a spill in sufficient time to collect enough evidence for the laying of charges if appropriate, and to provide coordination for the clean up to minimize environmental impacts of the spill.

Monitoring Network

The Ministry operates a Provincial Water Quality Monitoring Network of approximately 700 stations. This network is maintained to provide data for many uses including; water quality trends analysis, tributary load calculations from 65 major tributaries to the Great Lakes for reporting to the International Joint Commission, compliance and surveillance reporting, water quality assessments for Certificates of Approval, and as input to water quality models. Samples are taken on a routine basis by Ministry staff, by hired private citizens, and by Conservation Authority staff under special arrangements with the Authorities. The data from this vast network are analyzed and archived at the Water Resources Branch and are available upon request. As part of the arrangements with the Conservation Authorities the finalized data are copied back to them so that they are kept up to date on the water quality within their jurisdictions.

Water quality alone does not provide the full picture of the status of Ontario's streams. The essential component to complete the picture is a knowledge of stream flow. As part of the Canada-Ontario cost sharing agreement a network of between 400 and 500 streamflow stations is operated within the Province. Staff from the Conservation Authorities again provide an essential service in maintaining these stations. The finalized data are available upon request from either the Water Survey of Canada or from the Water Resources Branch of MOE.

Inland Lakes Program

Lakes are an essential component of many river systems and should not be left out of the picture. The Ministry recognizes this need and through its Inland Lakes Program it provides the same type of sampling network and data information program as exists for streams through the network program. The Inland Lakes Program, centered in Dorset relies heavily on cooperative efforts from the people in Ontario. Through this program private citizens take routine samples at fixed locations in lakes and submit them to the Ministry labs for analysis. This provides for an excellent sampling grid, particularly on the large recreational lakes where environmental impacts would have the greatest public impact. Many of you may recognize this as the old Self Help Program.

The above is a very brief summary of only a few of the many programs administered by the Ministry of the Environment. In the final section of this presentation I will attempt to paint the picture of how the Ministry wants to be seen in the role of managing Ontario's streams.

Part IV

Managing Ontario's Streams

If we think back to the goals of the Ministry presented in Part I of "...achieving and maintaining a quality of the environment..." and "...ensuring a fair sharing of

available resources..." then the Ministry can be viewed in the role of policing the environment. This immediately brings to mind a picture of environmental "cops" investigating and enforcing rules against environmental "bad guys". While the Ministry does have this capability through it's Investigations and Enforcement Branch and will use this "force" if necessary, it certainly is not the image the Ministry wishes to portray. The Ministry would rather be known as a good guy working with the people of Ontario for the people of Ontario.

From the information presented by my colleague from the Ministry of Natural Resources, the information which I have presented to you, and the information which my colleague from the Ministry of Agriculture and Food is about to present you will see that the mandates of our three Ministries and the Conservation Authorities overlap a great deal. This often leads to confused public and sometimes even more confused public servants; a somewhat less than ideal situation.

A project to review the watershed plans of the 38 Conservation Authorities which were submitted to MNR was recently completed by the Ministry of the Environment. The key issue which was identified in all of the plans was a requirement for consolidated direction from the government to the Authorities in putting together a plan to appropriately manage Ontario's streams for the greatest benefit of existing and future generations.

The concept of Integrated Watershed Management is beginning to be examined with MOE and elsewhere as the means of ensuring the required direction. In the past, watershed studies have tended to be done in a piecemeal fashion in which several agencies have worked independently to solve problems which fall within their own mandates. Frequently the proposed plan addressed each individual problem but did not address the watershed as a whole. Under the concept of integrated watershed planning and management the land/water interactions will be examined. Proposed management practices focussing on both water and land use will be required to ensure the successful management of the water resources. Studies would be carried out by a multi-disciplinary team involving key provincial ministries including MOE, MNR, OMAF, MAH and the CA. Other ministries, municipalities, private interests, etc., would also be involved at appropriate points in the process. The Conservation Authority could play the lead role in identifying the key problem areas and issues of concern. The agencies who have the expertise would then examine the problem and develop an action plan. The core group composed of experts from each of the participating agencies would then be responsible for integrating the plans into a master watershed plan which would consider the whole ecosystem. Trade-offs between plans to provide the best possible watershed solution would have to be worked out within the core group. Implementation should be overseen by a group reflecting the interests of all participating agencies. Funding for the implementation should also be shared amongst all the agencies involved.

This is a very idealist approach but a necessary one. The time for stream management on a "fix it as the problem arises" basis is past. The time for whole watershed integrated planning is here. It will take time and a lot of negotiations to get all of the government and agencies to agree to such a strategy. Most people feel that the wheels of progress turn very slowly, but who knows. If one examines the structure of the Beaches program it can be seen that this represents an attempt at this type of integrated management which is progressing very well; therefore the

wheels are already in motion.

In closing I would like to leave you with a quote from Henry Ford concerning an idealist. He states "an idealist is a person who helps other people to be prosperous". If we take this in the light of stream management then the ideal situation would be a planning strategy which strives for and achieves the best for all concerned. Let's all try for it, maybe we can find utopia.

The Role Of The Ontario Ministry Of Agriculture And Food In Water And Stream Management

Len Senyshyn, Water Quality Specialist
Ontario Ministry of Agriculture and Food,
Soil and Water Management Branch

OMAF's Mission

Recently, the Ministry has finished its strategy for the decade until 1995. The mission of OMAF is defined in Strategy as to:

> Encourage an efficient and competitive agriculture and food sector and protect and enhance the natural and human resources of this sector for the well-being of all people in Ontario. (Ontario, Sept. 1986)

OMAF's Soil and Water Strategy

Four strategic areas of the strategy were identified: Competitiveness, Financial Stability, Education and Training and Soil and Water. This strategy is the first to explicitly recognize the importance of rural soil and water resources to the agricultural industry.

The soil and water management strategy of OMAF includes:

- Review and analyze all of the legislative, regulatory and program framework of the Ministry, and eventually the government, to evaluate the impact on soil and water priorities by farmers.
- Provide basic research, knowledge and transfer of technology to primary producers to enhance long-term capacity of soil and water resources.
- Coordinate efforts of internal staff with other ministries, the federal government, other public agencies, institutions and the public to encourage proper soil and water use.
- Develop managerial and technical abilities within all segments of the industry to ensure sustainable use of soil and water resources that will aid the long-term competitiveness of agriculture.
- Provide public information to primary producers and others about the importance of proper soil and water resource management leading to a "stewardship" of resources focus by all users within the industry.
- Examine new technologies for proper handling and use of farm chemical, waste materials disposal, and cropping and livestock practices to maintain a competitive edge and to maintain sustainable resource use.

All of these actions can be used in reference to stream management, as it impacts on agriculture and as agriculture impacts on stream management. Whether

any particular point in the above strategy is applied is not important. What is important is that the management of soil and water resources is given the same emphasis as the traditional economic and educational thrusts of the Ministry. What is also important is the consistent reference to "long-term", "sustainability" and "stewardship" and "proper soil and water resource management" found in the description of the strategy. This reflects an attitude that recognizes the broad impacts of agricultural activities on soil and water resources, and a commitment to manage these impacts.

Agriculture: A major water user

The use of water resources by agriculture can be broken into four major areas:

Crop production

- the primary source of water for crops is from precipitation
- drainage of excess water, especially in spring, about 1.2 million ha of land is serviced by subsurface drains, an estimated additional 1.5 million ha would benefit from drainage (Broughton, 1976)
- irrigation for moisture deficiency (generally only in high valued crops) 52,000 ha irrigated of total of 4,095,000 ha of improved farmland or 1.3%

Livestock production

- safe drinking water for livestock
- sufficient quantity and quality for sanitation

Aquaculture

- sufficient quantity and quality for cold water species

Domestic uses on the farm

The Soil and Water Management Branch

The development of the Soil and Water Management Branch demonstrates the changing approach to soil and water resources management in the Ministry. With signing of the Canada-U.S. Agreement on Great Lakes Water Quality in 1978, the impact of agriculture, specifically soil erosion, on water resources significantly increased in prominence within the federal and provincial governments. The increased focus on water management and the related workload resulted in the formation of the Water Management Unit within the Capital Improvements Branch.

As it became clearer that a close working relationship between the staff dealing with soil and water management was required to meet the new demands on agriculture, as well as the Ministry, the Drainage and Water Management section of the Capital Improvements Branch and the Soil Survey and Soil Conservation sections of the Plant Industry Branch were combined to form the Soil and Water Management Branch.

This change in organizational structure emphasized the growing realization that the management of soil and water resources could no longer be considered simply as a component of crop production, but that it must be dealt with as an issue on its own merits and comprises broader societal, as well as agricultural, objectives.

The Soil and Water Management Branch is organized into four units:

- Soil Survey (which operates under the federal-provincial umbrella of the Ontario Institute of Pedology) - sampling, analyzing, classifying, mapping of soil resources.
- Soil Conservation - extension regarding soil conservation structures and conservation tillage.
- Drainage Administration - administer the Drainage Act, Tile Drainage Act, Tile Drainage Installation Act.
- Water Management - develop policies, conduct studies, provide advice regarding water management issues.

Programs:

OSCEPAP II (Ontario Soil Conservation and Environmental Protection Assistance Program)

Provides grant assistance for controlling agricultural soil erosion, sustaining crop productivity and protecting water resources.

Soil Stewardship Program

Encourages landowners to adopt farming systems that are sustainable in the longer term; systems that produce at a level that can be continued over time without degrading the air, soil or water resources. Provides funding for financial assistance, education, and research for soil conservation activities.

Tile Drainage Act

Provides for low interest loans to enable farmers to finance the installation of tile drainage on agricultural land.

Agricultural Tile Drainage Installation Act

Provides the authority to licence and regulate the tile drainage construction industry.

Drainage Act

Provides a mechanism by which landowners may attempt to obtain outlet drainage for their lands. It also provides financial assistance to the owners of agricultural land to offset the costs of drain construction and maintenance.

Ontario Drainage Works Erosion Control Program

Provides added funding (80% grant) for the purchase of materials used for erosion control in municipal drains constructed under the Drainage Act.

OMAF and Stream Management

Stream Management can be divided into management and runoff management or what gets into the streams. OMAF's role in instream management is limited to its responsibilities under the Drainage Act. OMAF has a larger role in runoff management. OMAF encourages and assists farmers to control the runoff from their properties. It makes sense from two perspectives: clean runoff into streams improves stream quality, and retaining soil and nutrients on the land ensures under sustained productivity.

The Drainage Act

The Drainage Act is the major OMAF program affecting instream management. "Instream" refers only to those watercourses designated as municipal drains under the Drainage Act.

For economic crop production adequate drainage is essential. Excess moisture in the growing season will hinder growth, and at planting or harvesting time excess moisture may prevent machinery from moving on the field without compacting the soil and increasing erosion.

Under the common law, non-riparian landowners do not have the right to collect mere surface water and drain it onto adjacent property. (If the water flows in a natural watercourse they are riparian owners.) Therefore, a process had to be developed by which non-riparian owners could attempt to provide adequate outlet for draining their land.

The Drainage Act is the descendent of Ontario statutes dating back to the mid 1800's that provide a legal procedure for landowners to attempt to obtain improved drainage for their lands.

Under the Act, there are 3 ways that landowners can seek to obtain outlet drainage. The most common of these is the petition process whereby the landowners are required to obtain a petition of the majority of those in the area requiring drainage (or owning 60% of the land requiring drainage) and present it to municipal council. If the council wishes to proceed with the petition, it will hire an Engineer to prepare a report showing the design of the works and the assessment of the costs. The Engineer in preparing the report will survey the area, become informed of the needs of the landowners in the area requiring drainage and learn of any other factors which must be considered in the report. If the report is accepted and work is to proceed, the municipality will enter into a contract to have the work done.

Council is required by the act to inform the landowners at several stages of the progress of the petitioned works. The right to appeal the decisions of council and the Engineer is provided at many stages in the process. The local Court of Revision, the Ontario Drainage Tribunal and the Ontario Drainage Referee hear the various different types of appeals.

In southern Ontario, a grant of one third of the costs assessed against agricultural land is available.

A number of studies done to date show that, overall, drains constructed under the act are cost beneficial. Some municipal drains have, after the fact, been found not to be cost beneficial in some analyses carried out. It is OMAF's philosophy that, given that the majority of drains constructed under the act have been shown as beneficial and the relatively low capital cost of most drainage works ($40,00 on average), detailed benefit-cost studies are not required for each project. However, the Engineer is expected to report to council if it is clear that costs would exceed benefits or if the proposed works are not required or impractical. For cases in which the municipality or the Minister believe a benefit-cost study is warranted, they may request and pay for such a study.

Works under the *Drainage Act* are exempt from the *Environmental Assessment Act*, but there are provisions for environmental appraisals. An environmental appraisal can be requested by a local municipality, conservation authority or Ministry of Natural Resources. The environmental approval may cover only those aspects

of concern to the party requesting it. The environmental approval must be paid for by the party who requested it.

OMAF's role is to facilitate the process by providing administrative advice to municipalities and engineers, education for landowners, appointing and funding the Ontario Drainage Tribunal and the Drainage Referee, and providing, with the cooperation of other agencies, design and construction guidelines for the use of engineers.

The Design and Construction Guidelines were first distributed in 1981 by OMAF and subsequently revised by a multi-agency committee and distributed by the Province in 1987. The Design and Construction Guidelines are written in recognition of the many, sometimes conflicting, interests and factors which must be considered in the design, construction and maintenance of works under the Drainage Act. Main topics addressed are planning the works, topographic and soils survey, hydrologic design criteria and consideration, hydrologic design methods, hydraulic design of channels and crossings, erosion and sediment control, fish and wildlife conservation, water quality considerations, and construction and maintenance measures.

OSCEPAP II, Soil Stewardship Program and OMAF Activities

OMAF's activities in runoff management include the OSCEPAP II program, the Soil Stewardship Program that was recently announced, and policy activities. Examples of policy activities include the current development of a federal-provincial accord on soil and water management, interministry protocols on how to address and control farm pollution incidents, and review of other OMAF programs to determine their potential effect on water management.

The OSCEPAP II provides grant assistance for controlling agricultural soil erosion, sustaining crop productivity and protecting water resources. It provides funding for a wide range of soil erosion control structures, manure storages, milkhouse washwater disposal systems, pesticide handling facilities and the establishment of permanent vegetation on highly erodible lands. Each year $5.5 million is available for OSCEPAP II projects.

The Soil Stewardship program was announced at the last throne speech and the details released on August 20, 1987. The program provides financial assistance for:

- soil building and maintenance-including diversification from row crop production, reforestation and retirement of fragile lands;
- structures - improvements of existing open municipal drains, enhanced grants for existing programs, tile drainage installation and soil conservation structures;
- machinery and equipment-rental, purchase or modification of residue management equipment and training of operators;
- technology transfer-grants for training courses and preparation of factsheets and brochures.

The program also provides funds for research into stewardship practices and the establishment of a Chair in land stewardship at the University of Guelph.

Conclusion

What is the role of the Ministry of Agriculture and Food in water and stream management? The primary role of the Ministry is to provide financial and technical assistance to producers to manage water resources to improve agricultural productivity and to manage the impact of agricultural practices on water resources.

Water management, including stream management, is a multi-disciplinary activity that must reconcile the different, and sometimes conflicting interests of many parties. The agriculture and food sectors of the economy are among these parties, and the Ministry of Agriculture and Food represent their interests. Agriculture is a major user of Ontario's water resources. In our multi-use water management environment the concerns and interests of the agricultural sector must be taken into account and balanced with those of other users.

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Policy and Synthesis for Municipal Interests

B.J. Poulton, P. Eng., Design & Construction Engineer, City of Guelph

I shall first acquaint you with a little of Guelph's history in storm water management - how we got to where we are today.

In 1970, the Ministry of Transportation and Communications, in partnership within the City of Guelph, embarked upon a project to construct a new Highway No.6 alignment through the City. This project, known as the Hanlon Parkway, required the construction of over 6 miles of 4-lane expressway within the City limits. A portion of this highway crosses through a conservation area known as the Hanlon Creek.

In order to minimize the impact of the Highway construction upon the Hanlon Creek Watershed, the partnership commissioned the University of Guelph to conduct an ecological study. The study team was charged with making recommendations for actions to be taken or alterations in highway design to be made for the purpose of minimizing the ecological impact of the highway upon Hanlon Creek and vicinity.

Although the study was first commissioned to review the impact of the highway, the team's terms of reference were expanded to include the review of the affect of total urbanization of the watershed.

The result of the team's efforts produced an extensive report entitled the "Hanlon Creek Ecological Study". The report recognized the existing encroachments on the watershed and attempted to accommodate the proposals for future land development while maintaining the then current state of the biological life support system. The report attempted to leave open the broadest range of alternatives possible for future use, including the option to habilitate threatened life support systems. It is this report that is the "raison d'etre" of the City's storm water management program.

That tells you how we got to where we are today and I think its worthwhile for me to spend just a few minutes on Guelph's particular manner of carrying out subdivision development.

Unlike the majority of municipalities in Ontario, Guelph carries out the design and construction of all services (sewers, watermains and roads) to be owned by the City upon completion of the Plan of Subdivision. The developer pays for the services but the City Engineer's Department calls the servicing contract and manages it throughout the construction. Some of you may be familiar with this style of subdivision servicing but I think most of you would be more familiar with the subdivision servicing process whereby the developer, through his Consulting Engineer, services the property to Ministry of the Environment and Municipal standards, and then turns the subdivision over to the Municipality upon completion of the servicing - a Performance Bond is usually involved to guarantee completion of the works.

the subdivision over to the Municipality upon completion of the servicing - a Performance Bond is usually involved to guarantee completion of the works.

As part of the subdivision development servicing process and in accordance with the criteria set out in the "Hanlon Creek Ecological Study" the City requires all developers to implement erosion and siltation control to the satisfaction of the City. This is, of course, of particular interest to this group here today, and I will spend the rest of my time in discussing Guelph's current practices. We will take a look at how well they are working and try to identify their shortcomings and see if there is room for improvements.

Since starting into subdivision development in the Hanlon Creek Watershed we have had various different schemes presented by developers. It should be noted that although the City designs and constructs the services, the developer is responsible for designing, constructing, and maintaining the erosion control and siltation measures to be used during house construction. Erosion control required as a result of the servicing construction on the streets is the responsibility of the City.

Going over the various schemes that we have allowed over the last 15 years, the erosion and siltation control can be broken down into three basic forms.

The first method consists of long ditches immediately adjacent to the road allowance which drain to a designated lot held out of development and upon which is located a siltation pond. Although this method does work, it is subject to disruption as the house builders proceed to carry out their work on the individual lots and can only be effectively maintained in operation if each and every house builder is prepared to maintain the ditch across his lot or alternatively place a culvert there to allow the free passage of any run-off waters. I know of no instance in my experience where a builder has put in a culvert. They would rather attempt to maintain the ditch and for the most part they fail in this effort and the ditch run-off ends up on the road and in the sewers. Another problem associated with this method is that the developer invariably wishes to sell the lot held out of development and we are constantly asked to free up these lots and designate some other lot as the site for the pond.

The second basic form takes the shape of medium length ditches or swales draining to a designated lot held out of development. This method also suffers the same problems as the first wherein the swales and ditches are constantly subject to disruption by the activities of the house builder and the developer invariably requests that lots held out of development be redesignated and other lots substituted for them. But, because the ditches or swales are of shorter length the disruption is not as consequential as in the first method since less drainage area is affected. This method does lend itself well to the situation where one builder is building on all the lots affected by the sub drainage area and can co-ordinate his building starting at the upstream and working downstream towards the pond.

The third method most often used is where the sub drainage areas within the subdivision are allowed to sheet drain to the road allowance and then this drainage is directed to large sedimentation ponds immediately upstream of the Municipal recharge ponds. These ponds collect the silt during the house construction and then are eventually eliminated as the housing construction is built out. The sedimentation ponds are usually located on to 2 or 3 subdivision lots held out of development until such time as the siltation pond can be removed. This last method is the method to which we are tending these days since it allows the builders the most freedom

ment until such time as the siltation pond can be removed. This last method is the method to which we are tending these days since it allows the builders the most freedom on the lots and removes the need to redesignate lots held out of development. This method is supplemented with at source control at critical erosion prone locations in the subdivision by using filter berms, straw bale berms and/or silt fences.

The one thing that has certainly become very evident is that any scheme is only as good as the developers inspection makes it. In almost every instance to date, developers have had nil to thin inspection and only at the behest of the City has inspection been done at all. The only clout the City has with the developer is to stop the issuance of building permits if the erosion control method is not working properly. Unfortunately, this hurts builders and new home owners as well. Also, because in Guelph the builders are not the developers, each subdivision has numerous builders, not just one. This leads to problems because the builders know how compliance is being enforced in other subdivisions throughout the City and not dealing equitably with all builders is often used as an excuse for non-compliance.

I do not intend to get into great detail about effective erosion control devices as there is now plenty of literature related to this subject, not the least of which are the guidelines put out by the Urban Drainage Policy Implementation Committee's Tactical Sub-committee No.5 dated March 1983.

The problems that we have are not technical engineering problems - the problems are related to a municipality's ability to put the technology to work. As stated on Page 5 of the guidelines, "the whole process relies heavily on the individual municipality, and because no specific measurable objective has been defined, (to avoid costly and time consuming monitoring) there will be a degree of judgement to be exercised". Well to say the least, this is difficult to work with since the developer's opinion is at one extreme while the municipality's is likely at the other extreme.

These guidelines also state that "good housekeeping" should start as early as possible on the site. However, the developer may actually start stripping his land long before the City has any control over the developer through a subdivision agreement.

Once the draft plan approval is received by the developer, there is nothing to stop him from proceeding to area grade his property before requesting a subdivision agreement from the municipality. Even if the Minister has stated, as a condition of the draft plan approval, that no construction is to take place before an erosion and sedimentation control report has been approved by the Municipality and the Conservation Authority, the developer can, and in my experience usually does, begin with impunity.

At this point, the Municipality does not have any authority to act nor does the Municipal Act have any provision for allowing a municipality to pass a by-law to effectively control erosion. In my opinion other provincial statutes could be used, in particular, the Ontario Water Resources Act. But to my knowledge it is not being used in these circumstances. Obviously, silt laden run-off reaching the stream may well occur during this phase of the development and could result in irreversible damage to the stream, notwithstanding any erosion control that may be implemented at a later date after the subdivision agreement has been executed. Given

the limitations upon a municipality under the present Municipal Act, the Provincial Agencies must take a greater role in this phase of the development process if the stream protection is to be provided.

Private property is exempt from an environmental impact at the present time and therefore damage to a local stream may be done before the Minister has even given draft plan approval. Again, control at this level cannot be carried out by the local municipality - it must be done by the Province.

I am very concerned about the statement made in the guidelines on Erosion and Sedimental Control for Urban Construction Sites which states that "the local municipality will be the sole reviewing and inspecting agency for erosion and sediment controls on municipal projects, other government agency projects and private developments within the local municipality's jurisdiction". The province is fooling itself if it thinks the municipality is going to take the ball and run with it from there. The trend today is appearing to be for the upper levels of government to pass off heretofore responsibilities of upper levels to the municipalities. This has recently occurred with the Ministry of the Environment and the "private sewer and watermain" amendments to the Water Resources Act. These amendments have dumped the control and inspection of projects on private property that require the approval of the Ministry of the Environment onto the municipalities regardless of their ability to do this or the impact on their financial resources.

How is the municipality to fund such inspection and how are we to make it stick? - certainly not through the subdivision agreements since this can only truly be enforced through the courts as a breach of contract, and this surely is not the intent of entering into a subdivision agreement.

Making statements about master drainage plans in an official plan is not implementing master drainage plans. Guelph has no master drainage plans at the present time nor is there any funding provided to produce them. If municipalities are to be encouraged to implement master drainage plans, how it this to be done?

If the erosion control problem is difficult within the subdivision process, it is next to impossible when it comes to dealing with large sites being developed merely upon application for building permits. Many large commercial and industrial sites are quite often larger in area than small plans of subdivisions. Just making the developers meet the requirements of the Building Code is a full time job for a large group of Municipal personnel, and if no staff is available for erosion control inspection, then it will certainly not be done.

It seems to me that the province must make changes to the Municipal Act which would give the municipalities authority to pass the appropriate by-laws for effective erosion control on any lands within its municipal boundaries if the province is expecting the municipalities to police erosion. If this is not done, then it must fall upon the province to ensure that erosion control is effectively enforced through its local Conservation Authority.

In closing, I would like to say that the challenge to each of us participating in a symposium of this nature is to share our knowledge and experiences in order to help identify the most important questions and issues to which our limited resources should be directed. Although the municipality of Guelph has, for a number of years now, been effective in erosion control related to subdivision development, we do need help from other agencies - especially from the Province, by way of adopting legislation to strengthen the municipality's ability to control erosion out-

side the subdivision process, if we are to have the ability to introduce the routine practice at the local level, rapidly and beneficially, the control of erosion and thus the protection of our stream heritage.

Stream Management In Ontario: The Experiences Of A Citizens Group

John F.B. Maher, Vice-President, the Black Creek Project

The beginnings of the Black Creek Project very closely resemble the pattern described by Lerner (1987) for stewardship groups. People with backgrounds in environmental studies, biology, engineering and nature photography became concerned about the future of our community stream as a result of apparent inaction by governments to protect it from the effects of unmitigated urbanization. Since 1982 we have developed from modest stream rehabilitation workdays to include a broad base of urban recreation interests and a variety of avenues of approach to achieving improved environmental quality.

Most of us were generally familiar with the effects of typical urban development on hydrology, water quality and aquatic life as described by Hall et al (1987). We were also aware of alternative ways to plan, design and construct urban facilities that did not create these undesirable effects, rather that developed runoff, ravines, wetlands and valleys for compatible uses in a multiple use approach. The reason these more progressive approaches were (and are) not being practiced in the Toronto area are not so much economic or technical as administrative.

The complex institutional environment in urban areas appears to be the major barrier to effective managment of urban natural environments. As Smith (1987) points out, while a water management agency (conservation authority) may have a mandate to manage a catchment for hydrologic parameters, the decisions that affect water management are taken by a host of other agencies (and corporations and individuals) who may have little or no interest or expertise in water. This plethora of decision making avenues is, of course, even more difficult an obstacle to a citizen group which depends entirely on volunteer work, usually on evenings and weekends. It was our initial impression that management of urban environmental quality along Black Creek was falling through the cracks between the various agency activites, and while there are now many more voices calling for coordinated action, the cracks are still far too large and the environment is still being destroyed faster than rehabilitation can be achieved. We have been paticularly frustrated by the responses to many of our rehabilitation proposals; as soon as dollars are mentioned we are referred to other agencies whose responsibilities overlap, but the circle never closes to complete the arrangements and get started. This is in marked contrast to more single-purpose groups such as Trout Unlimited who require contact with only one agency.

The Black Creek Project has managed to achieve substantial advances in the way developments have been designed and built in several cases. Each of these involved direct negotitations with a property owner or their agent when there was a legal avenue of recourse (such as an appeal to the OMB), or potential focus on the issue (such as an all-candidates meeting), that facilitated the initiation of negotia-

tions. Before such a situation was created, however, we found it very difficult to attract the attention of the people, planning, approving or building projects that affect urban environments. In recent years we have been contacted by some project developers early in the planning stages to provide input on our concerns; this is very much appreciated, and we believe such consultation will lead to a higher level of compatibility between these developments and environmental quality without significant increases in cost.

We cannot wait till all the studies by all the agencies and all their consultants are finished and a plan possibly accepted, funded and implemented. For one thing, since each agency is for the most part staying well within the boundaries of its mandate, each agency will tend to come up with single-purpose plans for remedial action. It is interesting to note, for example, how the Toronto area Watershed Management Study has produced a Humber River Water Quality Management Plan, which did not examine benefits of stormwater management options for aesthetics, wildlife, safety, fish habitat or recreation other than downstream at Metro beaches (Logan, 1987). Some citizen groups such as the Black Creek Project are ready to proceed with water managment plans that meet a variety of compatible objectives, and to try the best technologies economically reasonable starting now. This amounts to using the adaptive environmental assessment and management approach (Holling, 1978) and will require a fresh approach to cooperative planning and administration (Smith, 1987). The funding for water management projects should be obtained from the price charged for the supply of water, which is rather low at present in comparison to other commodities (Tait, 1987). The technical feasibility of the alternative approaches has already been established by research and practice in other jurisdictions, or on major projects (that are subject to the Environmental Assessment Act) in southern Ontario. These techniques and approaches are advocated, but not required during project reviews, by the regulatory agencies (M.O.E., M.T.R.C.A.), and described in guidelines issued by major project proponents (M.T.C., M.N.R., Ontario Hydro). Another source of frustration to citizens groups is the difficulty of finding out about, and being heard, on the majority of small projects (that together do most of the damage) that are not subject to the EA Act or are exempted via Class EA's (for eg., municiple water and sewer works).

To provide concise examples of the positive and negative experiences of the Balck Creek Project, the following "darts and laurels" are offered.

To the Ministry of the Environment: Laurels for major studies such as TAWMS to identify pollution sources and propose remedial action; Darts for keeping the studies secret until completed and not relating to other water interests. Laurels for research on better stormwater management techniques; Darts for requiring Certificates of Approval for ponds only if they attempt to improve water quality of runoff but not if there is no attempt (obvious incentive to developers to avoid building ponds that work as sediment traps).

To the Ministry of Natural Resources : Laurels for CFIP and CWIP that enable citizens to do hands-on improvements; Darts for funding only one CFIP project in Maple District in 1986 (MNR, 1987) and rejecting all CFIP proposals to date on Black Creek. Laurels for building urban fishing opportunities, improved access for the young, elderly and handicapped anglers; Darts for rejecting stormwater plans that would increase urban fish habitat and for the shortage of attention to urban fisheries improvement in district plans and license fund allocation.

To M.T.R.C.A.; Laurels for advocating contemporary stormwater management techniques; Darts for not requiring their use in the plan review process. Laurels for developing progressive land managment programs and public education programs such as at the Kortright Centre; Darts for allowing to continue the publicly held illusion that such programs are applied to the entire watershed area.

To the Town of Vaughan, M.T.R.C.A. and M.O.E.: Laurels for accepting a modified stormwater pond design that provides settling of sediments, retention of a Carolinian woodlot and space for a natural area to become established; Darts for allowing construction of services for a 1200 acre industrial development to proceed with no effective erosion control or management of runoff at source to protect water quality.

To Metro Parks: Laurels for keeping the middle third of Black Creek in attractive park conditions; Darts for allowing unsightly gabions and waste concrete to be used for bank protection.

To North York: Laurels for the Renaturalization Program to rehabilitate degraded parks; Darts for selling pieces of the valley to encroaching neighbours.

To the Ministry of Transportation and Communication: Laurels for developing the Drainage Manual to bring the state of the art to the project designers fingertips; Darts for not controlling highway runoff to intercept spills, salt and sediment; Laurels for developing new concepts in landscaping for rights of way; Darts for expropriating parks for a dollar to build roads, then selling the leftovers at market value for commerical development instead of using the space for water management.

Of course it is unfair to attribute credit or blame to whole agencies for our perceptions of the good and bad in their policies and actions, when the actions are in fact taken by individuals with their own attitudes toward environmental affairs. It is extremely difficult, however, for a citizen group with no staff to adequately discover even the basic levels of organization, let alone argue a decision, in agencies that are not well prepared to deal with the interested public.

Conclusion

The successes of the Black Creek Project indicate that stewardship groups can effect material improvements in the practice of urban development, if they are able to master the planning processes and muster the resources to participate. The complex planning process creates a large burden on urban stewardship groups to plan even the simplest projects, yet the criteria employed by funding agencies and foundations effectively prohibit the use of grants to hire staff for basic organizing purposes. We would advocate the establishment of a funding mechanism that would provide support to citizen groups to enable them to participate effectively in the planning process.